Benefit-Cost Analysis of Rural Roadside Countermeasures and Evaluation of the Roadside Safety Analysis Program

By

Sampath Kadiyala

Submitted to the graduate degree program in Civil, Environmental and Architectural Engineering and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering.

____

Chairperson: Dr. Steven D. Schrock

____

Dr. Thomas E. Mulinazzi

____

Dr. Alexandra Kondyli

Date Defended: February 27, 2017

Benefit-Cost Analysis of Rural Roadside Countermeasures and Evaluation of the Roadside Safety Analysis Program

By

Sampath Kadiyala

Submitted to the graduate degree program in Civil, Environmental and Architectural Engineering and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering.

Chairperson: Dr. Steven D. Schrock

Date Approved: March 7, 2017

DEDICATION

I dedicate this work to my parents for their guidance and support. You have been with me every step of the way, through good times and bad. Without their personal sacrifices and unconditional love I would have never become the individual that I am today. I love you with all my heart.

ACKNOWLEDGEMENTS

I would like to use this opportunity to express my sincere thanks to my advisor, Dr. Steven D. Schrock for his overall guidance, important suggestions, and constant encouragement at all stages of research. Being a mentor, he also helped and supported me throughout my entire stay at University of Kansas. I would also like to extend my gratitude to Dr. Thomas E. Mulinazzi and Dr. Alexandra Kondyli for serving on my committee.

I would like to thank the Kansas Department of Transportation (KDOT) for funding the research project and providing guidance at all times. I would like to thank my parents Subbarao Kadiyala and Surya Kumari Kadiyala, for encouraging me throughout all my studies. I sincerely thank my colleagues and friends for their continuous support and encouragement throughout my Masters.

Finally I cannot conclude this section without recognizing the support and affection shown by faculty and staff at KU while I was here. Thank you for being a part of this journey and making it ever so worth.

ABSTRACT

The roadside is a diverse environment having different types of objects with varying features. Roadway departure crashes can be severe and account for a majority of fatalities. In 2014, there were 17,791 fatalities (54 percent of traffic fatalities) associated with roadway departure crashes. On a rural highway, it can often be difficult for an engineer to install cost-effective countermeasures without accounting for the benefit of the potential countermeasure and the budget available. Primary objective of this thesis was to develop a series of figures to determine the cost-effective countermeasures for various considerations along the roadside of rural roads. Secondary objectives included exploration of the Roadside Safety Analysis Program (RSAP) and to examine any functionality differences between RSAP Version 2 (RSAPv2) and Version 3 (RSAPv3). Another research objective also included investigating the results of both of the versions and to provide future guidance for further exploration and development of the software. Different geometric and traffic conditions which generally exist in rural areas were selected to develop the required figures. Identical parameters were input in both versions to examine the disparities in benefit-cost ratio values and cost-effective countermeasures for each condition.

Roadside countermeasures that were selected for this research were: 1. do nothing (leaving the roadway unchanged); flattening the foreslope to 1:3 (from an assumed starting condition at a 1:1 foreslope); flattening the foreslope to 1:6; and installing the guardrail. These countermeasures were tested for different geometric and traffic conditions in both the versions. A detailed literature review was performed to study the previously recommended cost-effective options on roadside and research applications of RSAP. A questionnaire survey was sent to the state departments of transportation (DOTs) to determine the practical implementation of the software and benefit-cost countermeasures in practice on rural roadsides. Installation costs were calculated for every condition and road profile combination. The program was executed in both versions keeping the same input parameters despite the different procedures in RSAPv2 and RSAPv3. Benefit-cost ratio tables from both RSAP versions were compared, and it was found that results from RSAPv2 seemed to be more consistent and acceptable for this specific area of research. Negative benefit-cost ratios were generated for flattening the foreslope in the RSAPv3 analysis, which is impractical and, therefore, benefit-cost ratios of RSAPv2 were used for further analysis. Benefit-cost ratios of selected countermeasures under different geometric and traffic conditions were tabulated and

figures were developed. The developed figures are useful for local officials to determine the cost-effectiveness of potential roadside safety improvement alternatives for their specific conditions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 General Background

The roadside is a diverse environment having different types of objects with varying features. Vehicles sometimes leave the roadway and encroach onto the roadside facilities resulting in crashes. Roadway departure or run-off-road (ROR) crashes are sometimes severe and account for a majority of roadside fatalities. An ROR crash involves at least one vehicle that departs the traveled lane and encroaches onto the shoulder and beyond, and strikes one or more of any number of natural or artificial objects, such as bridge walls, embankments, guardrails, poles, parked vehicles, or trees. It is not always feasible to provide a clear-zone that is free of objects at all locations and under all circumstances. Even though the most desirable solution would be to keep the vehicle on the path, vehicles will continue to leave the roadway due to various factors that include driver inattentiveness, vehicle damage, and environmental conditions such as ice, rain or poor visibility. Roadway departure crashes can be severe and account for a majority of fatalities. In 2014, there were 17,791 fatalities (54 percent of traffic fatalities) associated with roadway departure crashes (*1*).

When it comes to rural highways, existing geometric features that can affect roadside crash severity may include foreslopes, backslopes, ditches, and culverts. On a rural highway, it can often be difficult for an engineer to install cost-effective countermeasures without accounting for the benefit of the potential countermeasure and the budget available. Benefit-cost analysis is one of the methods that can be used to decide where available funds should be spent to best achieve a safety benefit.

Flattening a roadside’s foreslopes is one of the countermeasures that can reduce the effect of ROR crashes. Foreslopes vary from non-recoverable slopes to recoverable slopes. Recoverable foreslopes are comparatively flat, where vehicles can recover when they depart from the roadway. Providing flat foreslopes can be expensive compared to steeper foreslopes. One of the major problem in any state, especially for rural roads is the transportation budget. Sometimes installing steeper foreslopes have a higher benefit-cost ratio than the flat foreslopes due to their lower construction and right-of-way costs. Sometimes there exists a condition where guardrail would be the best alternative on the roadside which prevents the vehicle running off the road and hitting an object. Therefore, there is a need for a methodology to prioritize the sites that require the utmost attention. The Roadside Safety Analysis Program (RSAP) is a tool that was used in this research to find the benefit-cost ratios for different alternatives at the same site under certain traffic and roadway conditions.

RSAP is an encroachment-based computer software tool for cost-effectiveness evaluations of roadside safety improvements which was originally developed as part of NCHRP Project 22-9. Three versions were developed, version 1 was developed in 1998 and was not widely used. RSAP version 2 (RSAPv2), a microcomputer based cost-effectiveness analysis procedure, was developed in 2003. RSAPv2 has two integrated programs: the user interface and the main analysis program. The main analysis program was written in FORTRAN and could run multiple simulations at the same time. The user interface was written using C++ and provided a more user-friendly interface through the use of multiple inputs and output windows within the software. In 2012, RSAP version 3 (RSAPv3) was developed which contained a major update of RSAP and was distributed with the AASHTO Roadside Design Guide (2011). RSAPv3 was developed based on Excel. RSAPv3 included the ability to analyze median crashes and allowed the user the ability to access and edit default input setting to account for regional differences or non-linear trajectories

1.2 Research Objective

This research was concentrated on finding the best cost-effective option among the following alternatives for different traffic and geometric conditions which were tested using both versions of the software. The alternatives tested include:

1. Do nothing (leaving the roadway unchanged – assumes 1:1 foreslopes);
2. Flattening the foreslope to 1:3;
3. Flattening the foreslope to 1:6; and
4. Installing the guardrail.

These four alternatives were tested for different design speeds, AADTs, fill heights, shoulder widths, and lane widths. Even though a rare condition, 1:1 foreslopes were used as the lowest starting condition to make the results conservative (if there is a need to upgrade from a worst case scenario). In addition, analysis included an investigation for starting at an intermediate option (such as 1:3 foreslope) and upgrading from that condition. Benefit-cost ratios for every condition were determined where one could find out the best cost-effective alternative for the specific geometric and traffic condition. Developing the simplified figures from the determined benefit-cost ratios was one of the main objectives. From these figures local officials can determine the cost-effective alternative among the four specified alternatives for the specific geometric and traffic condition without going through all the benefit-cost analysis.

1.3 Thesis Organization

This thesis is divided into six chapters. Chapter 1 introduces a general background on rural roadside and RSAP with the research objective. Chapter 2 provides a detailed literature review on roadside safety and application of RSAP on roadside countermeasures. Chapter 3 includes the questionnaire survey sent to DOTs and the summary of responses. Chapter 4 covers the RSAP software's (both versions) general functionality overall and also its application specific to this research. Detailed analysis is provided in Chapter 5 with developed figures to select the cost-effective alternative among selected alternatives. Conclusion and recommendations were included in Chapter 6 with future scope and application of RSAP.

CHAPTER 2. LITERATURE REVIEW

Roadside safety analysis is a standard methodology to evaluate the benefits and costs of a single or multiple countermeasures on roadside. RSAP is a computer-based tool that is designed to aid in the investigation of determining benefit-cost ratios for a single or multiple roadside countermeasures. This literature review summarizes research studies which evaluated the benefit-cost ratios for different roadside countermeasures in rural areas and the application of RSAP to analyze the roadside safety treatments.

2.1 Roadside Safety

Clear-zone is one of the main factors that controls ROR crash severity. The larger the clear-zone the lower the probability that a vehicle would hit an object on the roadside. The AASHTO Roadside Design Guide defined the clear-zone as "An obstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles." The Roadside Design Guide provides a clear-zone recommendation table shown in Figure 32 in Appendix B. Given AADT, design speed and foreslope the width of clear-zone can be determined from the table. The Roadside Design Guide also recommends the graph shown in Figure 1, which specifies barrier requirement for different embankment heights and foreslopes. It does not take traffic speeds, traffic volumes, or roadway geometrics into consideration. It recommends a barrier when the slopes are steeper than 1:3. Embankment slopes of 1:4 or flatter are less hazardous to the occupants of cars and provide an opportunity for an errant vehicle to recover. Even if the criteria of minimum clear-zone distance is met, sometimes highway sections with roadside hazards require additional safety countermeasures to be installed (*2*).

Hutchinson and Kennedy investigated the frequency, nature, and cause of vehicle encroachments into medians on divided highways. Vehicle departures into the median were collected for three-and-one-half years on various roadway sections in Illinois to determine the frequency and factors causing the encroachments. It was found that the frequency of encroachment increased with traffic volume until 4,000 AADT, and it started to decrease until a minimum value was attained at 6,000 AADT. It was also found that a 30-foot wide obstacle-free median with mild cross slopes was the minimum standard for the relatively safe stopping or control of vehicles encroaching on rural highway medians *(3).*

Mak provided a general overview of roadside safety, by collecting all types of ROR crashes (fatal and injury) that happened in 1989 in the US. The data were divided based on each type of roadside hazard. Collisions with fixed objects such as trees, poles, guardrails, etc., were found out to be hazardous roadside elements. This research provided an overall summary of the cost-effectiveness of treatments, a benefit-cost methodology, and different types of cost-effectiveness analysis procedures (*4*).

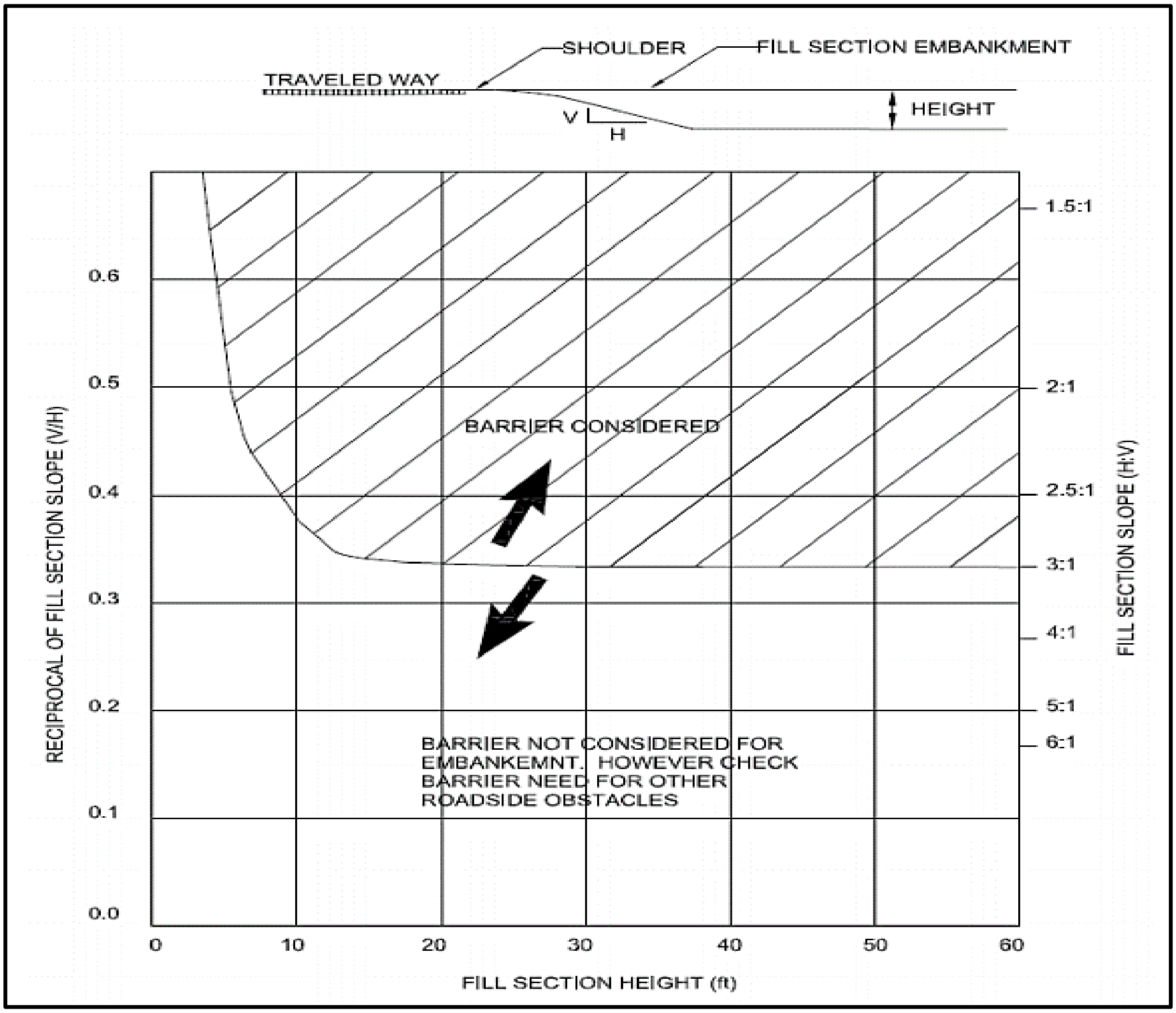


Figure 1. Barrier Recommendation Graph from Roadside Design Guide

Lee and Mannering investigated the relationships among roadway geometry, roadside characteristics, and ROR crash frequency. Roadside feature data were collected on State Route 3 (SR 3), in Washington State to identify potential severe roadside conditions. This research provided the empirical and methodological analysis of ROR crash frequency and severity. Two years of crash data on the highway were examined to determine the crash rate on various roadside features. These crashes were sorted by year and month and integrated with characteristic roadway data into one database. Three separate ROR crash frequency models for three different sections (i.e., total sections, urban sections, and rural sections) were selected to estimate the change in crash frequency for different roadway characteristics. A zero-inflated negative regression model was determined to be the most appropriate for estimating the crash frequency in rural sections. Likewise, the crash severity was determined for each ROR crash. Flattening foreslopes and medians, widening lanes, medians, or shoulders and relocating roadside fixed objects farther from the roadway were determined to be the alternatives which could reduce crash frequency and severity (*5*).

Zegeer et al. conducted a study on rural two-lane undivided roadways to determine the relationship between crash experience and cross-sectional characteristics. A crash prediction model developed in 1987 by Zegeer was used to predict the crashes. The crash reduction was determined for lane widening, improving roadsides, flattening foreslopes and bridge widening. Table 1 is the summary of the crash reductions for the above cross-sectional elements (*6*).

Table 1. Summary of Crash Reduction for Different Cross-Sectional Elements

Cross-Sectional Elements	Reduction in Crashes
Lane widening	40 percent reduction in related crashes
Shoulder widening	49 percent reduction for addition of 8 ft. paved shoulder
Roadside improvement	44 percent reduction for 20 percent increase in clear-zone
Flattening the foreslopes	27 percent reduction for flattening 1:2 foreslope to 1:7 or flatter
Bridge widening	80 percent reduction in bridge-related crashes

Miaou developed an ROR crash prediction model using real-world crash data. A roadway cross-section design database administrated by Federal Highway Administration (FHWA) and Transportation Research Board (TRB) was used to develop the model for rural two-lane undivided roads. The method described in the research was a practical approach to estimate encroachment parameters without actually collecting the data to estimate them. Crash frequencies were estimated using the model and graphs were drawn to determine crash frequencies for various factors like AADT, increase in lane width, shoulder pavement type, steeper sideslopes and number of driveways and bridges. A probability distribution of the lateral extent of encroachment was also derived using the model. Single vehicle ROR crash rates for a given sideslope per single vehicle ROR crash rate were determined as shown in Figure 2 (*7*).

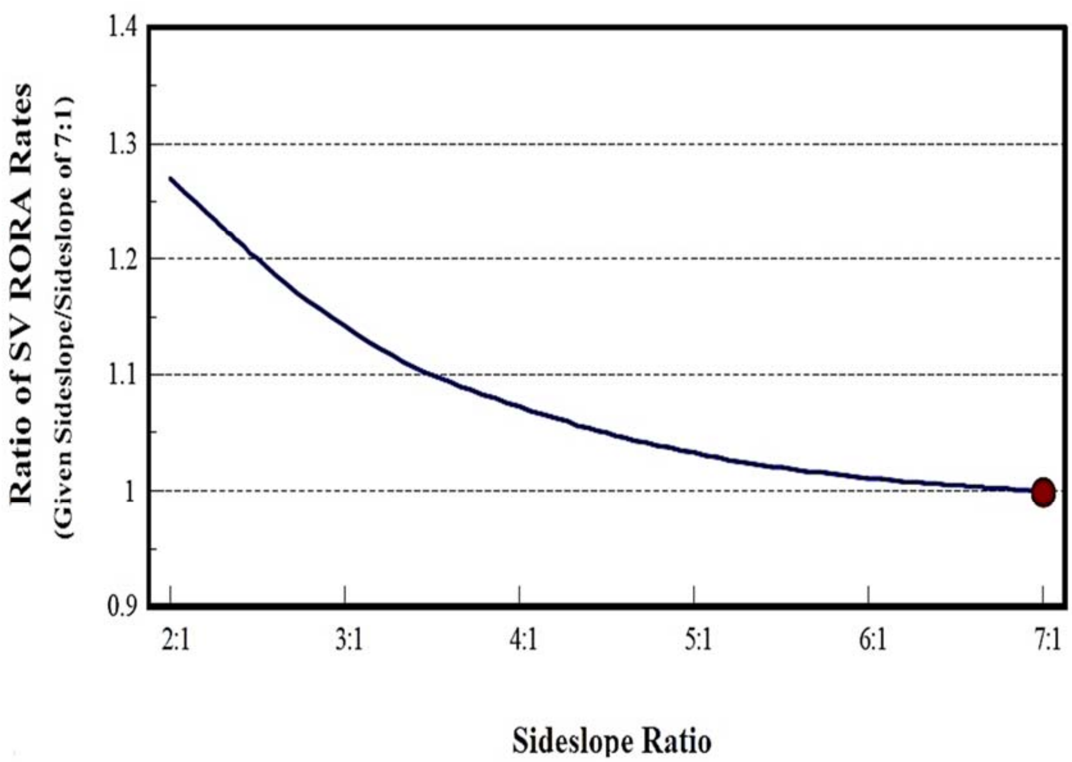


Figure 2. Single Vehicle ROR Crash Rate for a Given Sideslope Versus Single Vehicle ROR Crash Rate for a Sideslope of 1:7

Wu et al. developed nested logit models and mixed logit models to determine a correlation between ROR crash severity and driver behavior, environment, and geometric characteristics. Single-vehicle crash data from 2010 to 2011 in New Mexico were used to develop the models for both rural and urban segments. A total of 6,304 single-vehicle crashes in rural areas were used for estimation of the probability of injury severities. Both nested logit and mixed logit models showed similar outcomes for rural roadway segments. Fixed objects, overturning, rainfall, no passing zones, alcohol-impaired drivers, male drivers, and senior drivers were the conditions that were found to have a higher probability of severe injury and fatal-crashes. Animal-involved crashes, rainy conditions, crashes in no passing zones and pickup truck-involved crashes were more efficient in mitigating rural road injury severities when compared to urban injury severities (*8*).

Rys et al. evaluated the use of guardrails on low-volume roads in Kansas according to safety and cost-effectiveness. The ROADSIDE program was used to develop guidelines to determine whether a guardrail was needed on fill embankments and for shielding roadside obstacle on paved secondary roads. Data were collected on different types of culverts and different roadway conditions on low-volume roads. Different culverts and culvert ends were identified and were presented clearly with the cross-section of each culvert type. Different guardrails were determined, and the costs for installing them at various roadway conditions were identified. Based on an extensive literature review, it was determined by the researchers that guardrails were not economically justified for either 1:4 or 1:3 foreslopes with specific slope surface conditions, regardless of the design speed and AADT. The report concluded that the ROADSIDE program produced valuable results that should provide for a more cost-effective use of guardrail. The guidelines for guardrail were developed for different reinforced concrete box culverts. Guidelines for guardrails on low-volume roads with a culvert-pipe or headwall offset of 1.0 ft. and 2.0 ft. are shown in Table 2 (*9*).

Table 2. Culvert Cost-Effectiveness Results from ROADSIDE (Rys and Russell, 1997)

OFFSET* (ft.)	AADT	400 (vpd)	300 (vpd)	200 (vpd)	100 (vpd)
	Speed (mph)	Breakeven Culvert End Height			
1	50	NR*	NR*	NR*	NR*
	60	2.4 m	2.4 m	NR*	NR*
	70	2.4 m	2.4 m	NR*	NR*
	80	1.8 m	1.8 m	2.4 m	NR*
	90	1.2 m	1.2 m	1.8 m	NR*
2	50	NR*	NR*	NR*	NR*
	60	2.4 m	NR*	NR*	NR*
	70	2.4 m	2.4 m	NR*	NR*
	80	1.8 m	1.8 m	NR*	NR*
	90	1.2 m	1.8 m	2.4 m	NR*

NR* - Guardrail not recommended based on cost-effectiveness analysis

OFFSET* - A lateral distance from the edge of the roadway to the culvert

2.2 Economic Evaluation of Roadside Safety

2.2.1 ROR Crashes and Benefit-Cost Ratio

The AASHTO Roadside Design Guide provided a clear explanation of benefit-cost ratios and an economic evaluation of roadside safety. Besides design guidelines, the Roadside Design Guide also provided the following information on ROR crashes and benefit-cost ratios. Design features such as lane and shoulder width, horizontal and vertical alignment, sideslopes, and barriers on the roadside play a vital role to controlling ROR crashes. Extending the lane and shoulder widths can reportedly decrease the crash frequency and crash severity. Likewise, flattening foreslopes increases the probability of a vehicle coming back onto the roadway after running off the road. In rural areas, it is not always viable to provide the highest cost option because of budgetary constraints. So there is a need to identify the benefit-cost ratio for each possible countermeasure.

A benefit-cost analysis is the method to determine the benefit of installing one countermeasure over another countermeasure compared to the cost of installing the countermeasures. A benefit is measured in terms of reduced crash costs. The equation used for the benefit-cost ratio is

Benefit-cost ratio= $\frac{CC_i - CC_j}{DC_j - DC_i}$

Where

CC_i, CC_j = annualized crash cost of alternatives *i* and *j*, respectively

DC_i, DC_j = annualized direct cost of alternatives *i* and *j*, respectively

The benefit of installing a countermeasure is measured in terms of a reduction of crash costs. Reduction of crash cost sometimes results in a decrease in crashes and sometimes through a reduction of crash severity. Direct costs include direct construction costs, maintenance and right of way acquisition costs. A benefit-cost analysis should consider the time of the project and period of benefits for the project. Direct costs are converted to annualized construction costs using discount rates so that they can be compared with the annualized construction costs. The essential data needed for benefit-cost analysis was divided into three categories. They are:

1. Encroachments (number of vehicles running off the road);
2. Roadside geometry; and
3. Direct costs and crash costs*(2)*.

2.2.2 Benefit-Cost Analysis Programs

Mak and Sicking investigated different studies on benefit-cost modules, crash prediction modules and different programs used for benefit-cost analysis. Functionality and use of three major programs used are summarized in the following sections.

2.2.2.1 TTI ABC Model

The Texas Transportation Institute (TTI) in the mid-1980s developed the ABC computer program. The program incorporated a hazard imaging system that analyzed multiple hazards simultaneously. An array of speed and angle distributions from existing crash data and four vehicle types were used in the program to estimate the crash outcomes. The ABC model obtained the best possible prediction of impact conditions using the real world crash data. However, there were several limitations to the programs. Lack of a user-friendly interface and a large amount of data that had to be entered in a specific format (and no chance to correct the entered input) limited its recognition.

2.2.2.2 Benefit-Cost Analysis Program (BCAP)

In 1988 the FHWA modified the TTI ABC model to the Benefit-Cost Analysis Program (BCAP). Instead of using real-world crash data like the TTI model, BCAP used hypothetical data for crash prediction. The program incorporated algorithms that predicted vehicles rolling over a barrier and rolling over in front of a barrier. BCAP contained a Data Input Manager (BDIM), a user-friendly interface for the program. Despite a simple method for input data, the interface turned out to be complicated for editing. BCAP was not widely accepted because of the problems with BDIM.

2.2.2.3 ROADSIDE Program

ROADSIDE is a simplified version of BCAP developed by FHWA. ROADSIDE uses the same procedures as BCAP, but with several differences. The arrays used in BCAP were replaced by single vehicle size, impact speeds and angle distributions to reduce the program running time. The severity of crash was estimated as a function of impact speed and angle instead of crash severity estimation algorithms used in previous programs. It requires hand calculations for some of the adjustments in the input data, which were one of the reasons for limited acceptance (*10*).

2.2.2.4 *RSAP*

RSAP is a probability-based encroachment module which gives benefit-cost ratios for different alternatives. RSAP is used in this research to evaluate different cost-effective treatments for rural roadside safety. A detailed explanation of RSAP is given in the following sections.

2.3 RSAP

Currently, RSAP has two versions that can be used by practicing professionals including RSAPv2 which was developed in 2002 and documented in NCHRP Report 492, *Roadside Safety Analysis Program (RSAP) – Engineer's Manual*, which was published in 2003. RSAPv2 was based on an encroachment probability-based model and was also described as an innovative implementation of risk-based roadside cost-benefit design. RSAP became standard in industry practice, and it replaced many roadside design procedures and software. However, it became apparent that an updated version was still needed to fix identified errors and to improve the user interface. RSAPv3 was a significant update of RSAPv2, which is currently distributed with the AASHTO Roadside Design Guide. A similar benefit-cost analysis methodology is included in the updated version, however, with changes in the default data input fields and with new algorithms.

2.3.1 Overview of RSAPv2

RSAPv2 is comprised of two integrated programs, the user interface, and the main analysis program. The main analysis program was written in FORTRAN, and the user interface program was developed in Microsoft C++. The main analysis program performs processing of the data and the user interface program then processes the respective outputs and presents it to the user in both graphical and tabular data format (*11*).

2.3.2 Overview of RSAPv3

RSAPv3 includes the ability to analyze median crashes. Also, the program allows the user to edit default data within the software to account for regional differences, non-linear trajectories, the inclusion of new unique roadside hazards, and a new probability-of-collision model that uses real crash data trajectories from NCHRP 17-22 "Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes" data. RSAPv3 was written as a series of Visual Basic Applications (VBA) macros within Microsoft Excel. Additionally, RSAPv3 uses a conditional encroachment-collision severity procedure to determine the frequency, severity and societal costs of ROR crashes for each user-entered design alternative. The crash costs are then compared to the installation costs (both initial installation and maintenance costs) of the given alternative countermeasures. The alternative countermeasures with the highest benefit-to-installation cost are reported as the best alternative. RSAPv3 is comprised of four steps for assessing each alternative (*12*):

- Encroachment Module;
- Crash Prediction Module;
- Severity Prediction Module; and
- Benefit-Cost Analysis Module.

2.4 Use of RSAP to Analyze Different Alternatives

Schrum et al. collected seven years of real-world crash data and correlated the crash severity to embankment geometry. Foreslopes of 1:2, 1:3, 1:4, and 1:6 for fill heights 1 ft., 7 ft., and 13 ft. were considered for the analysis. The total roadside slope mileage was determined, and the data were finalized in the units of A + K (incapacitating injury and fatal) crashes per 10,000 vpd. All this information was used to calibrate Severity Index (SI) values of RSAP software for freeways, rural arterials, urban arterials, and local highways. Equations were generated relating the SI to functional class, fill height, slope steepness and posted speed limit. Roadside slopes had the highest SI values and fill heights of 7 ft. showed higher severity values than the 13 ft. fill heights. Overall, default SI values for foreslopes in RSAP were changed to reflect the real-world crash data. The research has shown that SI values were reduced on freeways, rural arterials, and urban arterials, and also for some slope-height combinations. It was concluded that SI values were believed to be indicative of real-world crash data (*13*).

Schrum et al. determined the severity indices based on the crash data collected. The default severity indices in the software were considered to be overestimated. The new SI was used in RSAP in different foreslope scenarios for different volumes and road conditions. Flattening the slope and increasing the offset decreased the crash costs for all functional classes. It was found out that slope flattening reduced the crash cost. The decrease in crash cost was observed when the foreslope was flattened from 1:3 to 1:4, which reduced the crash cost by 80 percent. Basically, three alternatives 'Do nothing,' 'flattening the foreslope,' and 'installing the guardrail' were tested in the analysis. It was found out that guardrail installation should only be considered after all possible slope flattening alternatives have been explored (*14*).

Ray et al. derived a methodology for systematically comparing longitudinal barrier performance. This paper discussed an empirical method to tabulate the vehicles involved in crashes which have contact with the longitudinal barriers. The crash data collected by empirical means were used in RSAPv3 to compare the observed crashes against the estimation of crashes. Crash data were gathered to evaluate the hazards. The three types of data collected and tabulated were: penetration, rollover, or vaulting (PRV) collisions, which are crashes that allows a vehicle to continue behind the hazard; rollover same side (RSS) collisions, collisions that do not cross the barrier and then roll over on the impact side of the barrier; and equivalent fatal crash cost ratio ($EFCCR_{65}$), which replaced the severity index in RSAPv3. These three values were determined for different median barriers. The tabulated values helped to compare the severity of each type of barrier crash; the probability of penetrating, rolling over or valuating and the probability of rolling over after the redirection. They found out that the RSAPv3 is predicting a higher crash rate than the actual observed crash rate data. The percentage of PRV collisions and RSS collisions were determined using RSAPv3 and compared to the gathered crash data (*15*).

Appiah et al. developed a simplified spreadsheet to determine the benefit-cost ratio for installing guardrail in different geometric and traffic conditions for low volume roads. A wide variety of input parameters can be given in the spreadsheet to determine the benefit-cost ratio to install a guardrail. The results of the spreadsheet were compared to those produced by RSAPv3. The comparison of results between the spreadsheet and RSAPv3 is given in Table 3. The correctly predicted proportion was determined to be 0.894 (*16*).

Total predicted = 12 + 64 + 97 + 7 = 180

Correctly predicted = 64 + 97 = 161

Correctly predicted = 161/180 = 0.894

Table 3. Matrix of Predicted and Actual Outcomes (Appiah and Cottrell, 2015)

		Actual (RSAPv3)	
		Not Cost-Beneficial	**Cost-Beneficial**
Predicted (Spreadsheet Tool)	**Cost-Beneficial**	12	64
	Not Cost-Beneficial	97	7

2.5 Summary of Literature Review

RSAP software (both RSAPv2 and RSAPv3) has been successfully used to evaluate roadside safety as shown in the previous literature, where there was a need to analyze multiple alternatives under different road and traffic conditions. Additionally, in the late 1990s research was conducted to compare RSAP with existing modeling programs such as ROADSIDE. RSAP was used to evaluate the cost-effectiveness of guardrails on low-volume roads, used to analyze the benefit-cost ratios of different longitudinal barriers, and also applied to work zone scenarios to assess temporary barriers. For each of these scenarios, guidelines were given for the best use of the roadside safety improvements for a particular type of roadway, indicating RSAP's utility as an evaluation tool. Research conducted on the performance of the software predicts that RSAP is sensitive to input parameters and RSAPv3 was found to slightly over-predict potential roll over and penetration crashes.

Graphs and test matrices can be prepared for different cost-effective alternatives by performing a large number of runs for different roadway and traffic conditions. With a probabilistic approach, one can compare the real-world crash data results with the model output to check all the parameters. Flattening the foreslopes was determined as one of the most cost-effective alternatives for increasing roadside safety. Guardrail is recommended in conditions where there are high AADTs, and crash rates. Decision matrices developed based on benefit-cost ratios would be helpful to determine the best cost-effective approach for different traffic and geometric conditions.

The literature search also indicated that there were no research studies that performed a direct comparison of the differences between RSAPv2 and RSAPv3, indicating a need for such an analysis.

CHAPTER 3. SURVEY OF PRACTICE

3.1 Survey Design

A regional survey was conducted which asked other state highway agencies, besides the Kansas Department of Transportation (KDOT), about their use of the RSAP software and their cost-effectiveness approaches regarding roadside countermeasures for all types of roadways. The developed survey focused on how many state highway agencies rely on RSAP to analyze roadside alternatives and the application of benefit-cost analysis on roadside countermeasures more generally. The survey consisted of the following seven questions:

- *Do you have a formal process to determine the cost-effectiveness of proposed safety improvements on rural roadside safety projects?*
- *If "yes" can you please explain the process?*
- *Do you use RSAP to analyze roadside safety alternatives?*
- *If you do not use RSAP, do you use some other type of software to analyze roadside safety alternatives? If so what?*
- *If RSAP was used, what version?*
- *If both RSAPv2 and RSAPv3 were in use, was either version used for specific purposes and any particular reason?*
- *Are there any specific types of projects that RSAP is used for?*

3.2 Survey Results

A total of 18 state highway agencies (Alabama, Arizona, Arkansas, California, Connecticut, Florida, Illinois, Indiana, Maryland, Massachusetts, Missouri, Nebraska, Ohio, Oregon, Texas, West Virginia, Wisconsin, and Wyoming) responded to the survey. Some of the agencies have the same process throughout the state, while some vary by district. Summaries of the answers to each question are presented herein.

Do you have a formal process to determine the cost-effectiveness of proposed safety improvements on rural roadside safety projects?

All the respondents had a formal process to determine the cost-effectiveness of proposed safety improvements. Six of the respondents (approximately 33 percent) reported using highway safety software or well documented procedures such as Crash Modification Factors (CMF) or by following the AASHTO Roadside Design Guide. Eleven of the respondents (approximately 61 percent) reported using either a software program developed for benefit-cost analysis for roadside safety, or using an in-house developed Excel worksheet to determine benefit-cost.

If yes, can you please explain the process?

Whatever method they reported in finding cost-effective countermeasures, all of them used the benefit-cost ratios at the end either by software or manually to find if an alternative was cost-effective.

Do you use RSAP to analyze roadside safety alternatives?

Eight respondents (Arizona, Illinois, Indiana, Maryland, Montana, Nebraska, Ohio, and Wisconsin) reported using RSAP either at a statewide level or in at least one district. This represented 44 percent of the surveyed states.

If you do not use RSAP, do you use some other type of software to analyze roadside safety alternatives? If so what?

Ten of the 18 respondents (approximately 56 percent) did not use RSAP to analyze roadside safety countermeasures. The Oregon Department of Transportation used the software BCAP developed by FHWA. Six of the respondents (approximately 33 percent) reported using the AASHTO Roadside Design Guide, and three used CMFs and manually calculated the benefit-cost ratios of potential safety improvements.

If RSAP is used, what version?

Although RSAPv3 was developed recently as stated in the previous sections, many respondents reported using RSAPv2 with some progress toward incorporating RSAPv3 into their safety program. The Alabama Department of Transportation (ALDOT) reported using RSAPv3, the Texas Department of Transportation (TxDOT) reported using RSAPv2 on some safety-related projects, but not for all rural roadside projects.

If both RSAPv2 and RSAPv3 were in use, was either version used for specific purposes and particular reason?

All respondents that reported using RSAP explained that they were not using a specific version for a particular reason. All of the respondents reported using RSAPv3 stated that they preferred RSAPv3 over RSAPv2 when there was an existing roadway cross-section which was not predefined in RSAPv2.

Are there any specific types of projects that RSAP is used for?

All of the respondents who reported using the program were found to mainly analyze projects related with culverts, foreslopes, backslopes, and high-tension cable median barriers on interstate highways.

3.3 Summary of Survey

All of the state highway agencies that responded to the research project survey (and that also reported using RSAP) were found to be transitioning to RSAPv3. Even though some of the agencies used RSAP to analyze the roadside issues, it was found not to be standard practice among all of the agencies at the time of this survey. Also, RSAPv2 was found to be preferred by state highway agencies for straight tangent roadway segments where RSAPv3 was the preferred software version where there was a frequent change in roadway cross-sections. The AASHTO Roadside Design Guide and in-house developed Excel worksheets were tools that were also reportedly being used to analyze the roadside safety in addition to or instead of RSAP.

CHAPTER 4. METHODOLOGY

This research study's primary objective was to develop a series of decision matrices to determine the benefit-cost estimates for proposed safety improvements using the modeling software RSAP. The research study's secondary objectives included synthesizing the RSAP results for both versions and determining if any trends emerged for further safety improvements. Additionally, an analysis was performed to determine if any differences were present between RSAPv2 and RSAPv3, and to provide guidance for future countermeasure exploration using RSAP.

4.1 Input Modules in the Software for RSAPv2 and RSAPv3

Since both versions of RSAP evaluated in this research study are built on differing software platforms, the procedure to input the data into each version was different. However, the data that were input into each version are identical. It was also found, however, that the program default values and predefined values in both versions were also different. The basic information required to run RSAP are part of five categories which included:

1. General information;
2. Highway and traffic information;
3. Geometric characteristics;
4. Cross-section information; and
5. Other miscellaneous information.

4.1.1 Input Modules of RSAPv2

The input modules for RSAPv2, including the cost, highway geometry and traffic segment characteristics, and roadside features for a specific project should be entered for each alternative. General information such as the project description, seed number selection, crash costs, vehicle mix and unit selection could be assigned for all of the alternatives at once.

4.1.1.1 General Information

Inputting the general information into RSAPv2 is shown in Figure 3, where the user inputs a project description and seed number for the project. The "seed" is a starting point for the program sequence, and the guarantee is that if one starts from the same seed, he/she will get the same sequence of numbers. Varying the seed number will provide slight variations in the output to reflect the variability inherent in crash analysis. A seed number of “1111” was recommended by the software development team to fix a known bug in the software coding.

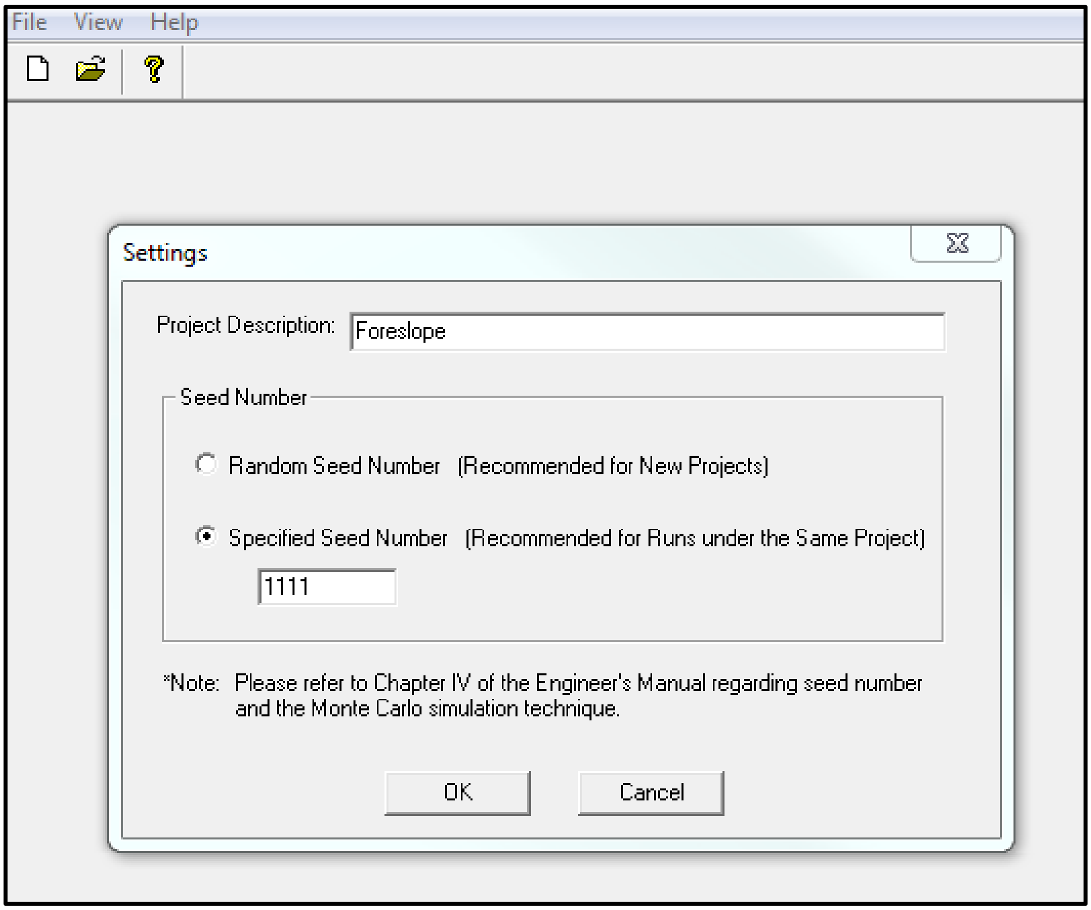


Figure 3. RSAPv2 General Information - Seed Number

Other general information that could be input by the user includes the life of the project, discount rate, installation costs, and maintenance costs. These values could be input separately for each alternative that will be processed by the software. The window in RSAPv2 where these values are inputted is shown in Figure 4.

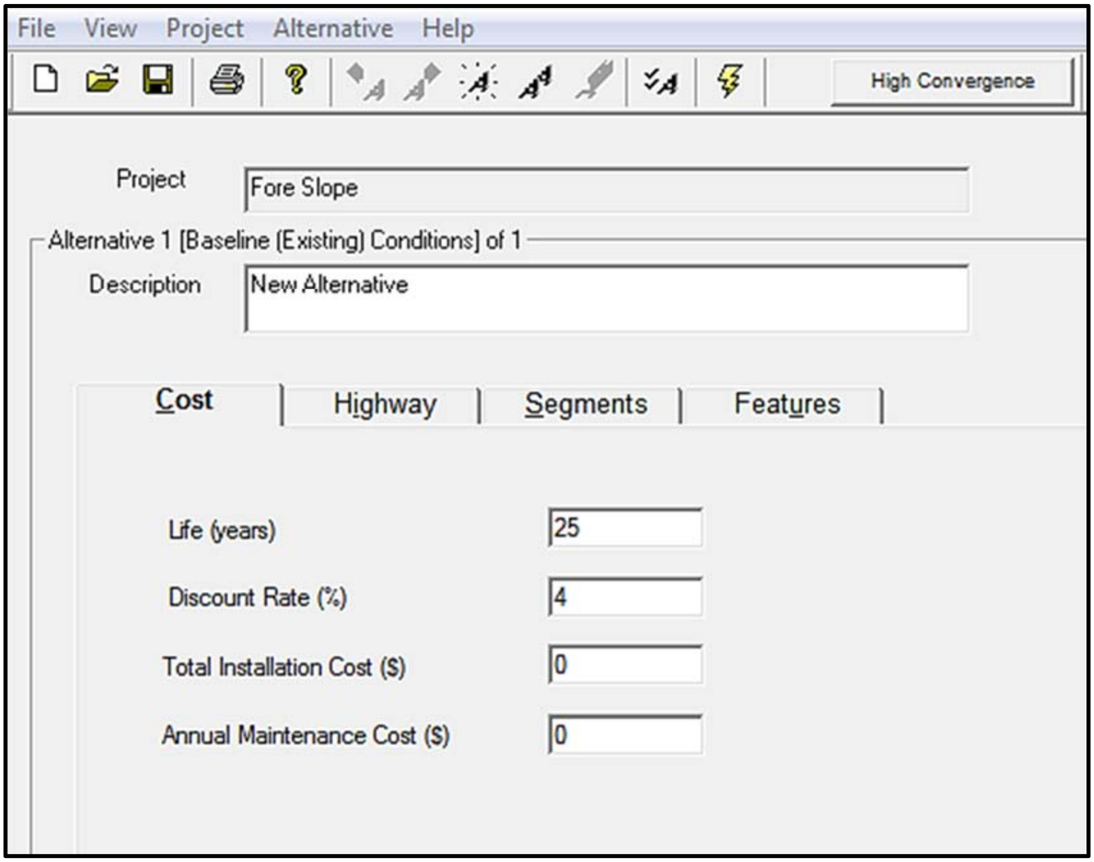


Figure 4. General Information - Life, Discount Rate, Installation Costs and Maintenance Costs

4.1.1.2 Highway and Traffic Information

Traffic and highway information are input into RSAPv2 software by the user. As illustrated in Figure 5, there is drop-down selection for area type, functional class, and highway type. For area type, the user can select from rural or urban. For functional class, the user can select from freeway, principal arterial, minor arterial, collector, or local roads. For highway type, the user can select from two-way divided, two-way undivided, and one way. All the other information shown in Figure 5 are given as per the conditions of the site being analyzed and should be input for each alternative.

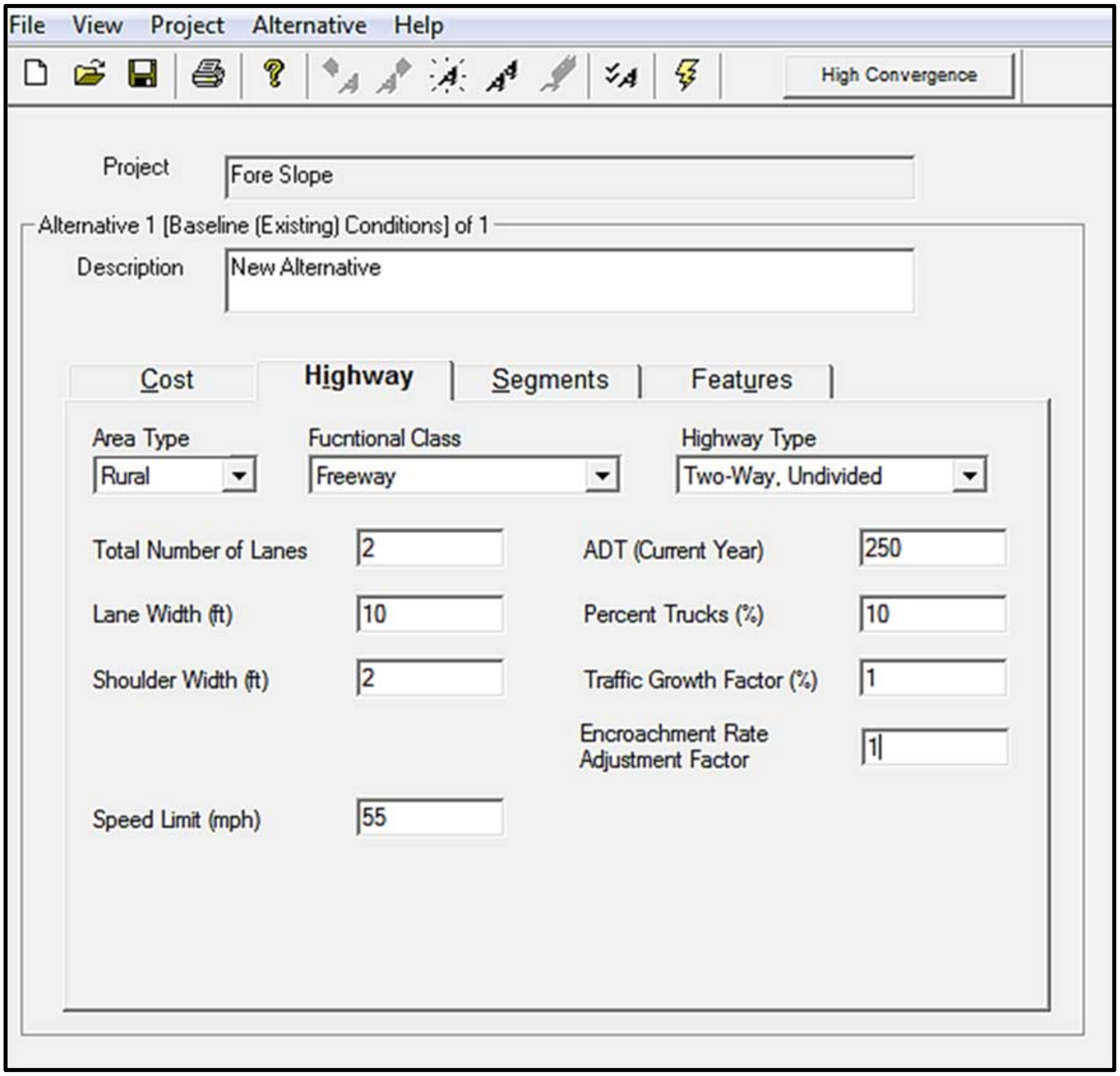


Figure 5. RSAPv2 Highway and Traffic Information

4.1.1.3 Geometric Characteristics

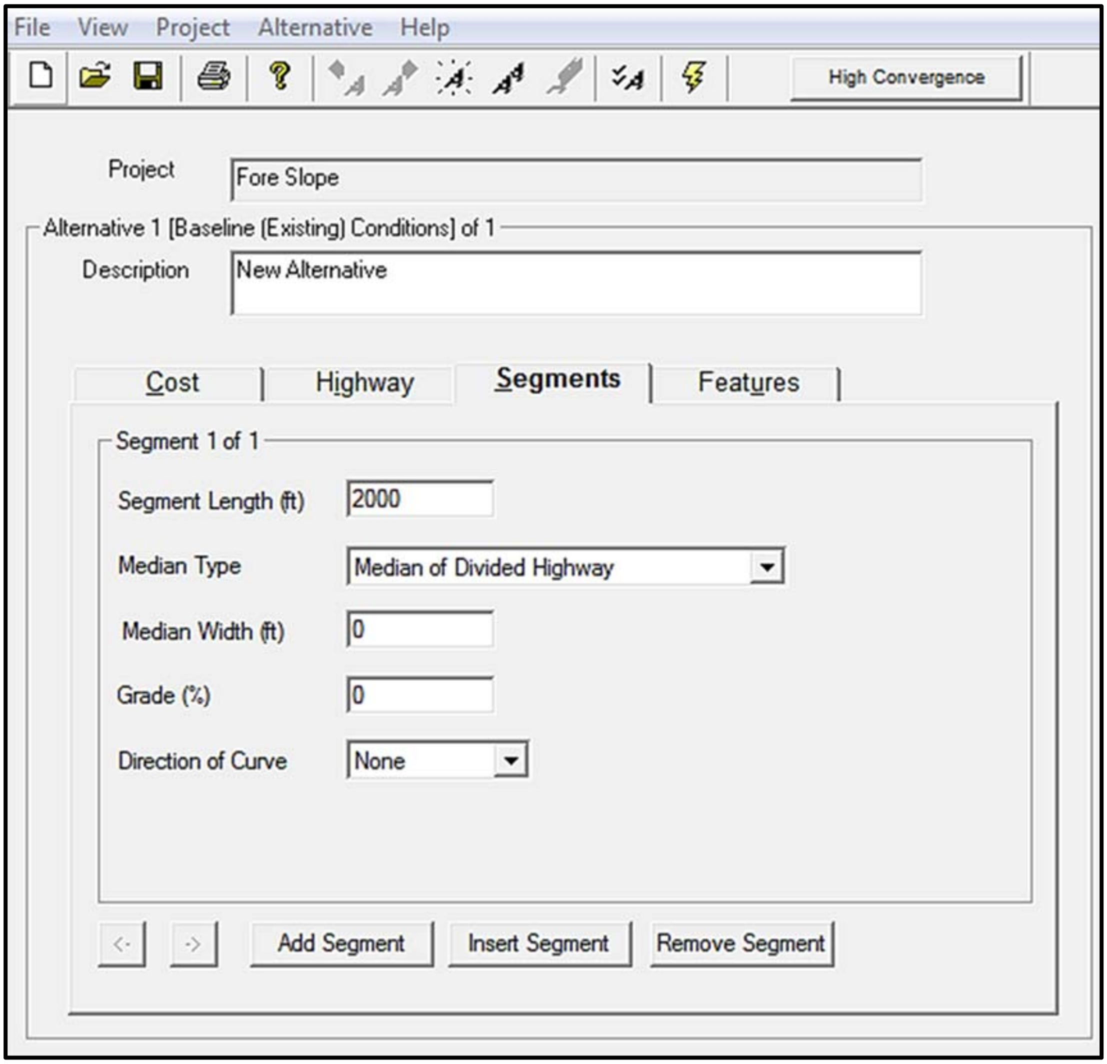


Figure 6. RSAPv2 Geometric Characteristics

Geometric characteristics are also required for each alternative and the window to input the data is shown in Figure 6. Segment length, median type, median width, grade, and direction of the curve (if applicable), segment length, median width, and grade are input by the user. A drop-down selection for median type includes median of divided highway, no median undivided highway, painted median undivided highway, two-way left-turn lane undivided highway, and a not applicable option. For the direction of the curve, the user can select none, right, or left. Additional segments can be added to the analysis by selecting "add segment."

4.1.1.4 Cross-Section Information

Cross-section details of a particular alternative can be given in the window shown in Figure 7. The roadside features are predefined in the software which can be selected under the section category, the different variations in a particular category can be selected from 'Type.' The following are the different roadside features that can be selected:

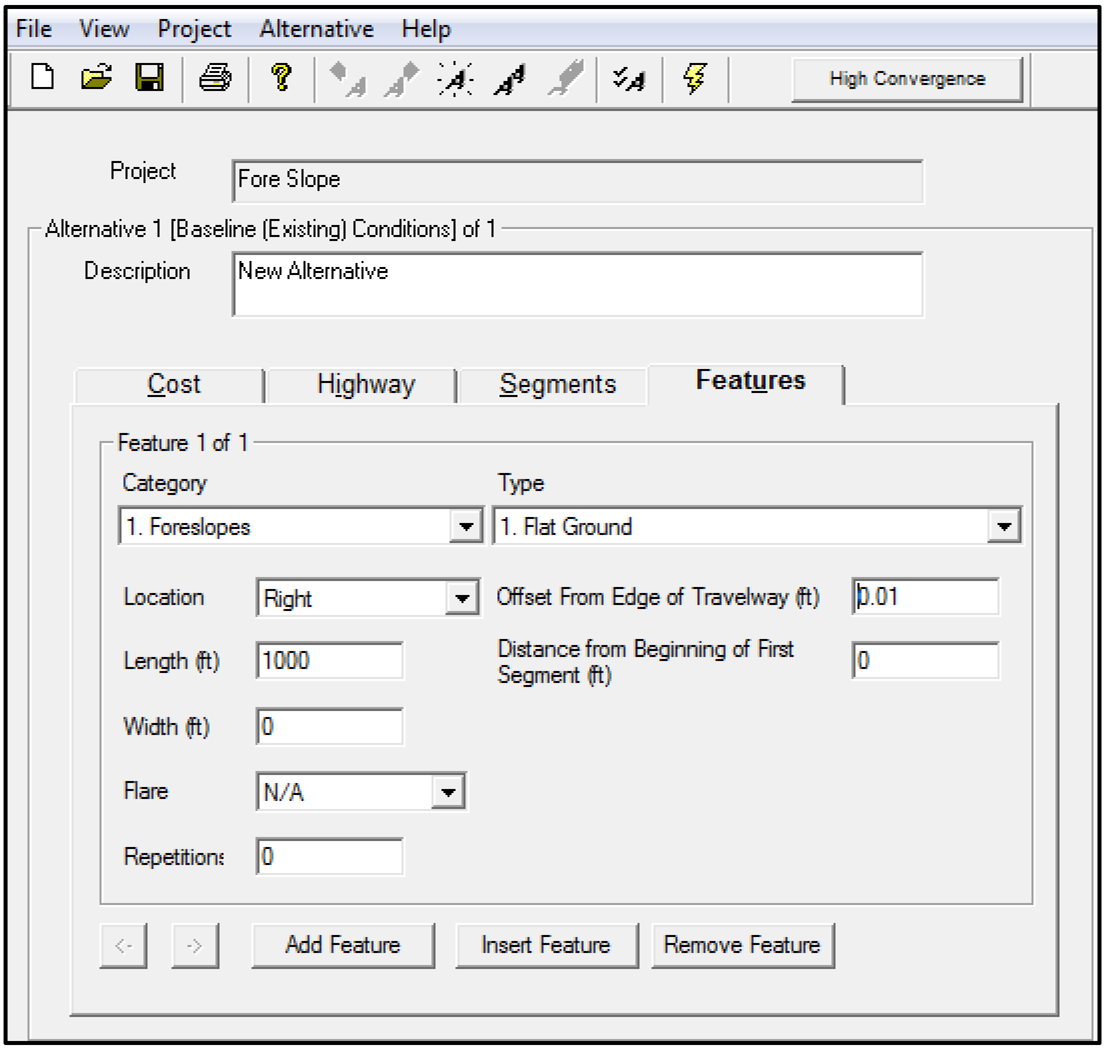


Figure 7. RSAPv2 Cross-Section Information

1. Foreslope with 54 different types such as 1:3 foreslope with 1 ft., 7 ft., 13 ft., and 20 ft., fill heights and 1:6 foreslope with 1 ft., 7 ft., 13 ft., and 20 ft. fill heights;

2. Backslope with 25 different types such as 1:3 with height greater than 3 ft. and height less than 3 ft.;

3. Parallel ditches with 12 different types such as 1:2 foreslope and 1:2 backslope and 1:2 foreslope and 1:3 backslope;

4. Intersecting slopes with 90 different types such as 1:3 (negative) with different heights and 1:2 (negative) with different heights;

5. Fixed objects with five different object types: round, rectangle, tree, wooden utility pole, and breakaway support with different dimensions for all of these objects;

6. Culvert ends with different types such as Type A, Type B, Type C, Type D, Type E with different heights for a total of 35 types (*10*);

7. Longitudinal barrier with five different types of barriers: guardrail, median barrier, portable concrete barrier, portable barrier and bridge rails of different types for a total of 17 types;

8. Terminals and crash cushions of 11 different types;

9. Miscellaneous includes roll over on top of barrier, roll over in front of barrier, and barrier penetration; and

10. User-defined features which can be given by the user, which is explained in the miscellaneous information section.

All these features may be on the right side of the roadway, left side of the roadway or in the median. The user can change this setup by changing the location in the window shown in Figure 6. Length, width, and offset from the edge of the traveled lane of each of the categories can be changed in the window illustrated in Figure 7. Flare rates can be changed to predefined options of downstream, upstream, and not applicable. The distance of the particular feature from the beginning of the first segment and repeating values can be changed manually. Features can be added, inserted, or removed by using options given at the bottom of the window shown in Figure 7.

4.1.1.5 Miscellaneous Information

Units, types of crash costs, vehicle mix, and editing features can be accessed through the 'Options' tab which appears by clicking the view button at the top of the window of the software. These values are the same for all of the alternatives and cannot be changed for an individual alternative. Units can be changed from English units to metric units, the types of crash costs that can be selected are:

- Roadside Design Guide Cost,
- FHWA Comprehensive Costs,
- User Defined Costs KABCO (K-Fatal; A-Incapacitating Injury; B-Non-Incapacitating Injury; C-Possible Injury; and O-No Injury), Fatal, Injury and Property Damage Only (PDO) as shown in Figure 8.

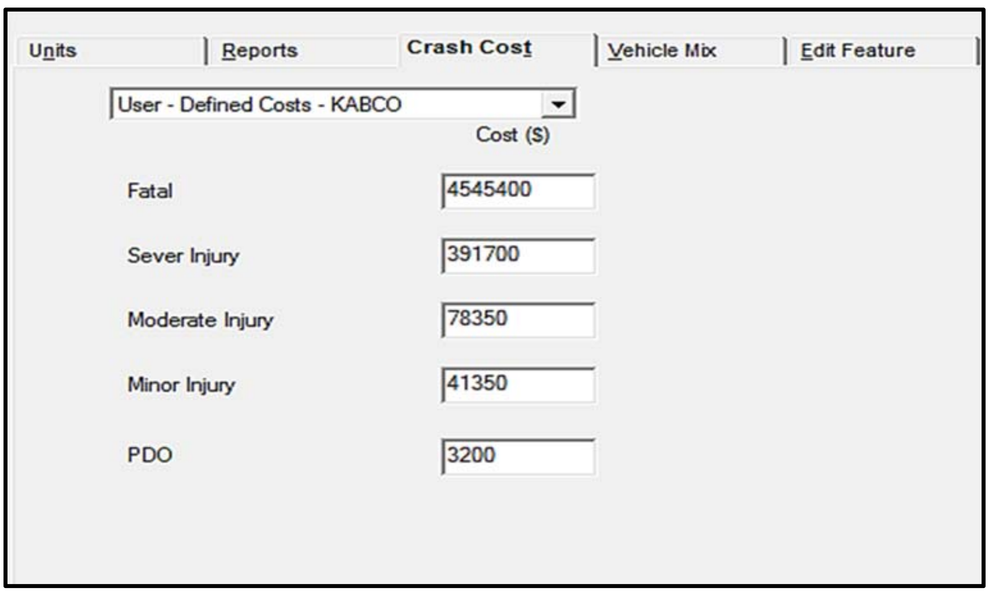


Figure 8. RSAPv2 Crash Cost-User Defined-KABCO

Vehicle mix can be changed with the options: Nominal Percent trucks, User-Defined Vehicle types, and User-Defined Vehicle Categories as shown in Figure 9. User defined features can be added as shown in Figure 10 and this edited features can be selected in the 'Features' tab for providing details for each alternative. The set of reports to be printed can be selected from the

'Reports' tab; the set of reports that can be selected are shown in Figure 11. The user can also set the level of convergence as high, medium or low in the 'Project' tab at top of the window.

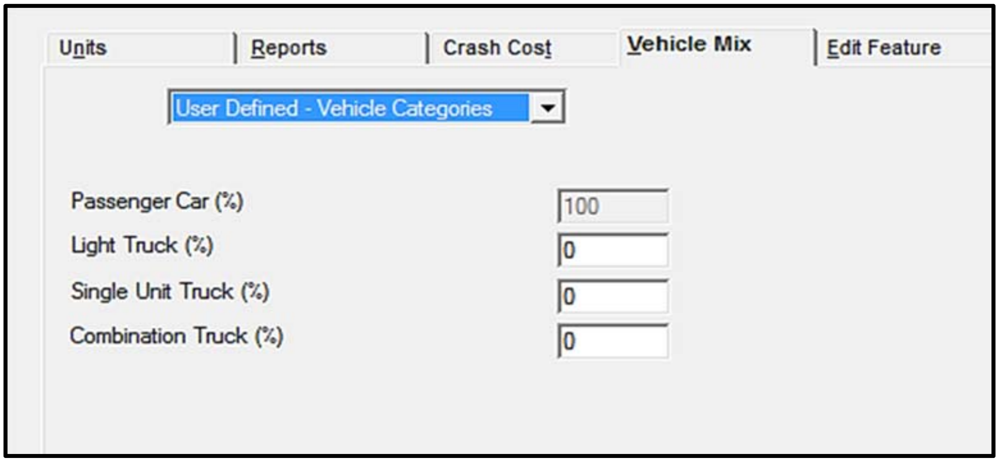


Figure 9. Vehicles Mix

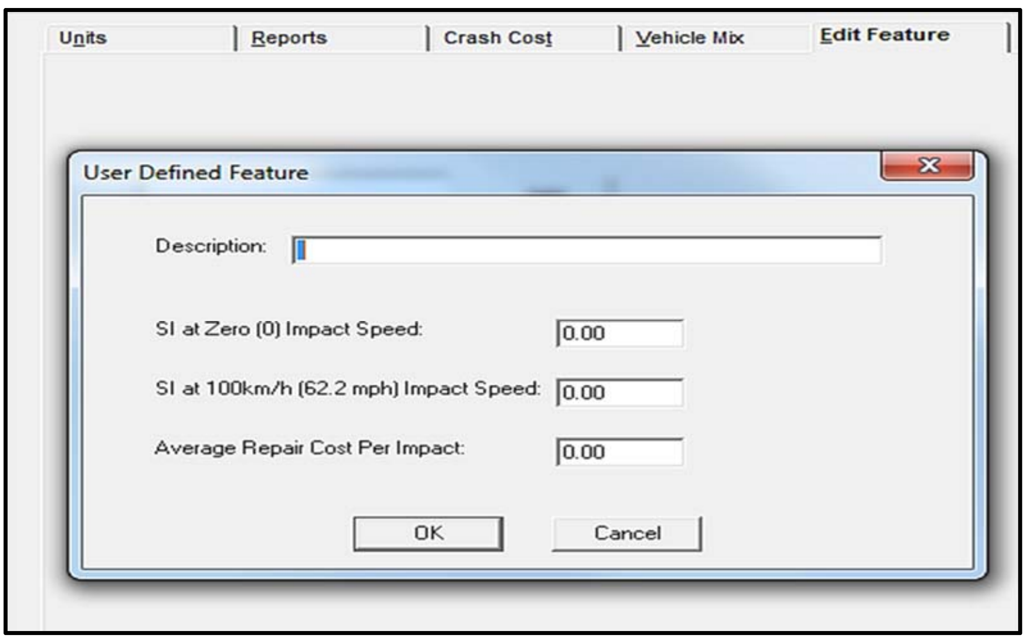


Figure 10. RSAPv2 Edit Feature Tab

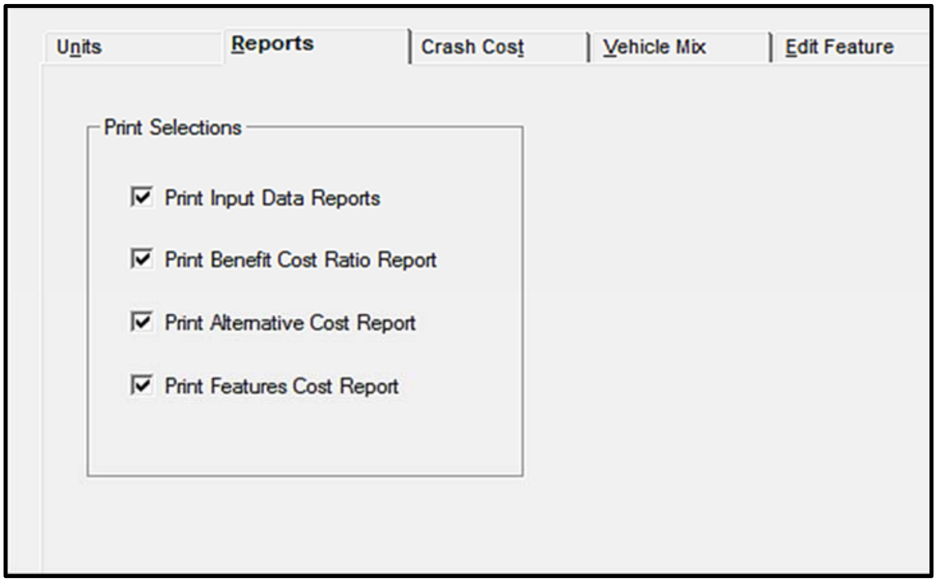


Figure 11. RSAPv2 Reports to be Printed

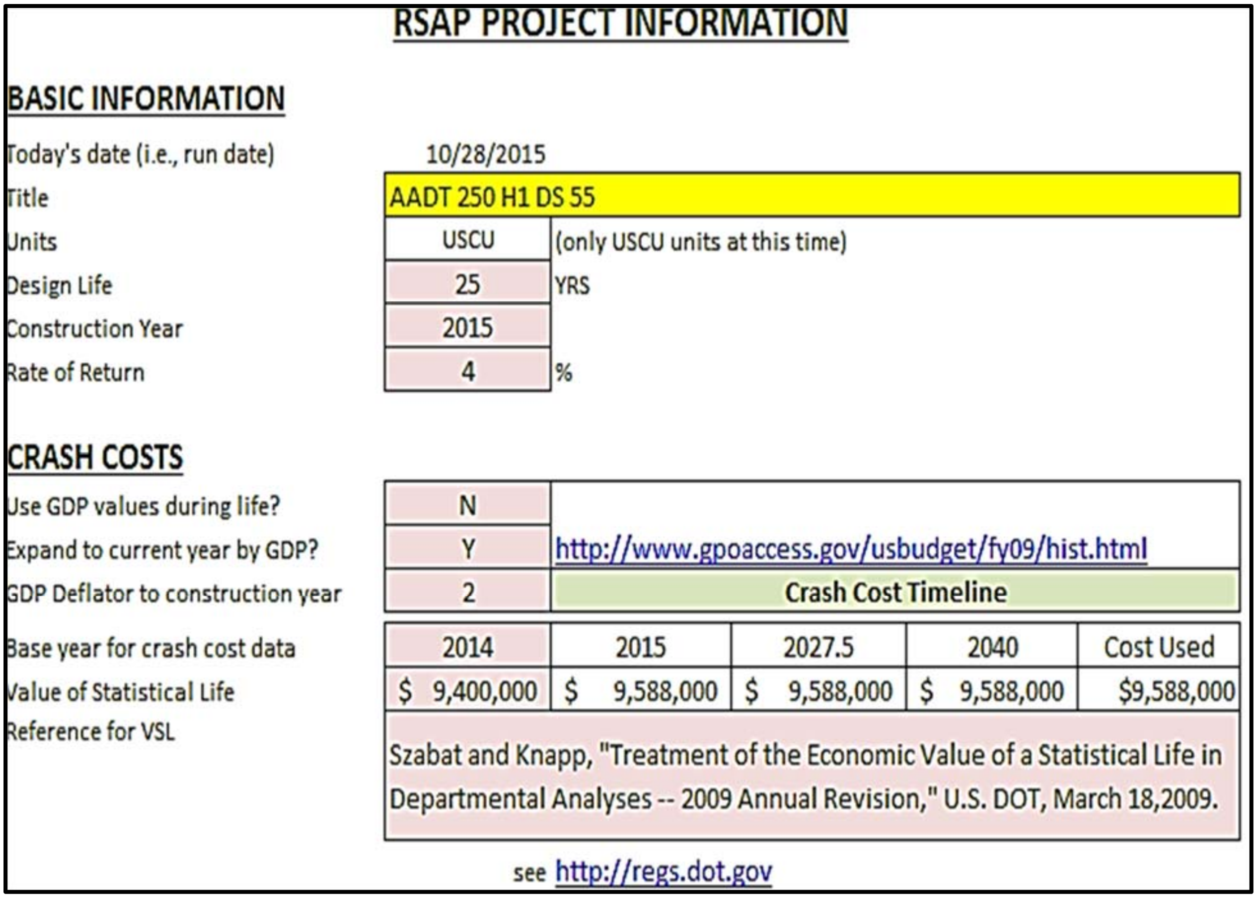
After all these values are inputted the user must select the 'Analyze' option to get the selected reports.

4.1.2 Input Modules of RSAPv3

In RSAPv3 the general project information and the traffic and highway information are input one for the whole project. The roadside features (or hazards) and cross-section information are defined and assigned to each of the alternatives. There is an RSAP controls window where the user can manage the different types of input information, including project, traffic, alternatives, and cross-section information. The actual values are given in the window shown in Figure 12.

4.1.2.1 General Information

The title of the project, design life, construction year, and rate of return are the basic information that is input into the window shown in Figure 12. The crash cost data for the whole project are also entered into the same window illustrated in Figure 12 where the value of a statistical life of a person is given instead of user-defined crash costs. Figure 12 is the window into which the user inputs general information.



RSAP PROJECT INFORMATION

BASIC INFORMATION

Today's date (i.e., run date)	10/28/2015	
Title	AADT 250 H1 DS 55	
Units	USCU	(only USCU units at this time)
Design Life	25	YRS
Construction Year	2015	
Rate of Return	4	%

CRASH COSTS

Use GDP values during life?	N				
Expand to current year by GDP?	Y	http://www.gpoaccess.gov/usbudget/fy09/hist.html			
GDP Deflator to construction year	2	Crash Cost Timeline			
Base year for crash cost data	2014	2015	2027.5	2040	Cost Used
Value of Statistical Life	$ 9,400,000	$ 9,588,000	$ 9,588,000	$ 9,588,000	$9,588,000
Reference for VSL	Szabat and Knapp, "Treatment of the Economic Value of a Statistical Life in Departmental Analyses -- 2009 Annual Revision," U.S. DOT, March 18,2009.				

see http://regs.dot.gov

Figure 12. RSAPv3 General Information of Project

4.1.2.2 Traffic Information

Traffic information can be input into the window shown in Figure 13 where the AADT, traffic growth, and the traffic mix of the vehicles on the roadway, crash costs adjustment factors, and encroachment multipliers can be edited.

AADT 250 H1 DS 55

TRAFFIC INFORMATION

CONSTRUCTION YEAR ADT:	250	vehicles/day
TRAFFIC GROWTH	1.0	% growth/yr
WHICH ADT TO USE?	Mid-Life	
MID-LIFE ADT:	283	vehicles/day
END OF LIFE ADT:	321	vehicles/day
ADT USED BY RSAP	283	vehicles/day

VEHICLE MIX

RSAP VEHICLES	FHWA CLASS	PERCENT	RSAP TYPE	TYPICAL CHARACTERISTICS					Crash Cost Adj.	Encr Multiplier	Mix Multiplier
				WEIGHT	LENGTH	WIDTH	C.G. Long.	C.G. Hgt			
		%		lbs	ft	ft	ft	ft			
Motorcycles	1	0.0	M	600	7.00	1.50	3.00	2.60	0.56	1.00	0.00
Passenger Vehicles	2	63.8	C	3,300	15.00	5.40	6.00	2.00	1.00	1.00	-0.75
PickupTruck	3	21.3	PU	5,000	19.75	6.50	8.50	2.30	1.00	1.00	-0.25
Light Tractor Trailer	8-9	0.0	LTT	16,000	48.00	8.50	12.00	4.8	3.52	0.30	0.00
Average Tractor Trailer	8-13	9.0	ATT	22,250	48.00	8.50	20.00	4.8	3.52	0.30	0.60
Heavy Tractor Trailer	8-13	0.0	HTT	37,500	48.00	8.50	20.00	6	3.52	0.30	0.00
Light Single Unit Truck	5	0.0	LSUT	6,800	35.00	7.77	12.50	3.4	3.52	0.30	0.00
Average Single Unit Truck	6	6.0	ASUT	12,000	35.00	7.77	12.50	3.4	3.52	0.30	0.40
Heavy Single Unit Truck	7	0.0	HSUT	22,000	35.00	7.77	12.50	4.2	3.52	0.30	0.00
Total		100.00									0.00

Figure 13. RSAPv3 Traffic Information

4.1.2.3 Highway Characteristics

When given the highway characteristics, the user provides the whole roadway characteristics in the window shown in Figure 14 and then provides the highway characteristics as shown in Figure 15. Undivided, divided, and one-way are the highway types that can be selected. Flat, rolling, and mountainous are the three terrain types that can be selected from the ‘Terrain’ option.

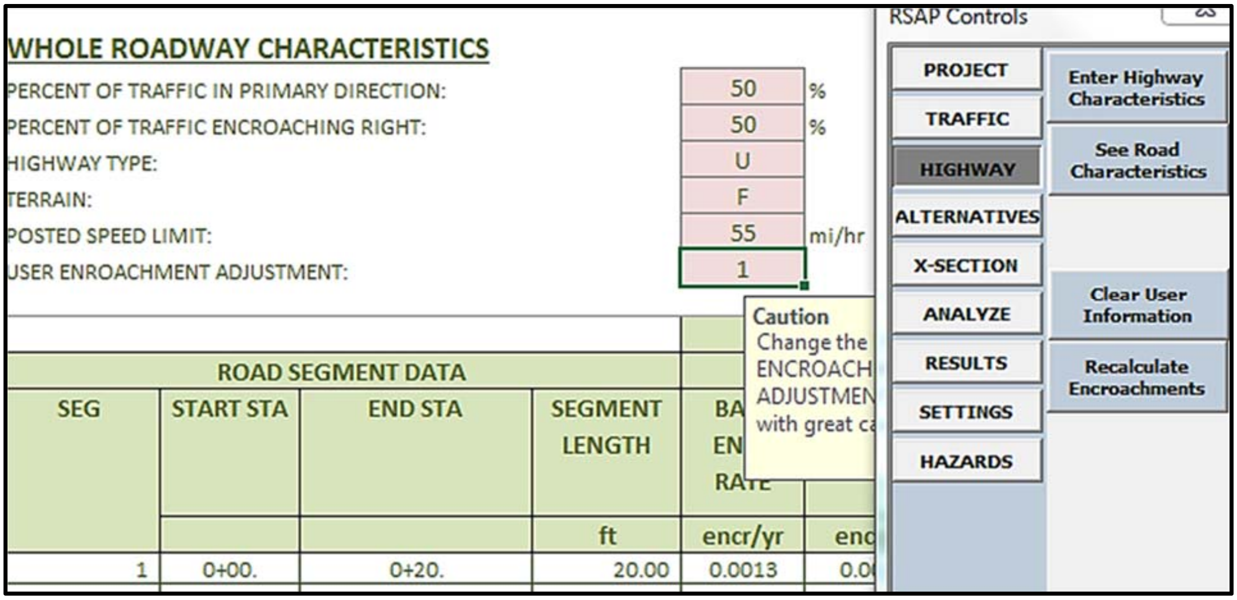


Figure 14. RSAPv3 Whole Roadway Characteristics

While choosing the 'Enter Highway Characteristics' option on the other 'Whole Roadway Characteristics' window on the right-hand side in Figure 14, the following window will appear where the user can give the geometric characteristics of the highway.

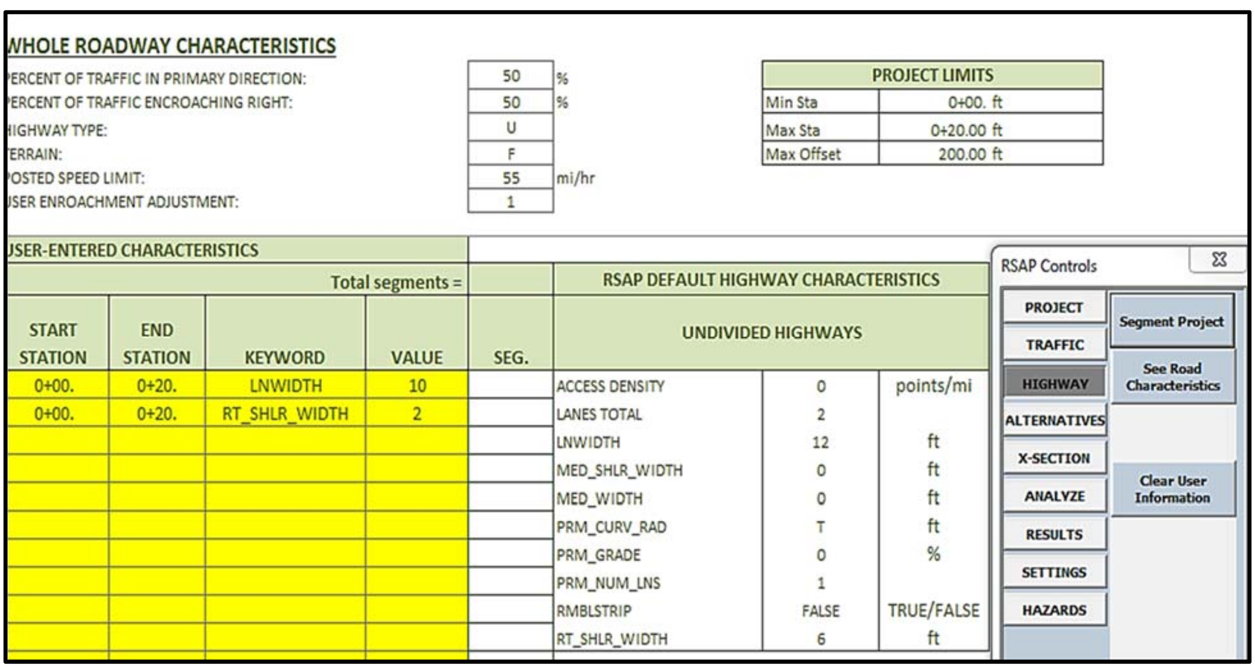


Figure 15. RSAPv3 Geometric Characteristics

The highway characteristics that can be provided in the ‘Highway Characteristics window are: access density, total lanes, lane width, median shoulder width, median width, primary curve radius, primary grade, primary number of lanes, rumble strips, right shoulder width, and cross-section. Choosing the ‘Segment Project’ option in the ‘Whole Roadway Characteristics’ window on the right-hand side in the Figure 15, the project can be segmented into parts based on its geometric characteristics.

4.1.2.4 Roadside Features

In the ‘Alternatives’ tab shown in Figure 16, roadside feature or hazards can be input with the following data: start station, start side, start offset, end station, end side and end offset. For each alternative, the following data input areas are also provided; alternative name, construction cost, annual installation cost, and default cross-section. The type of hazards that are predefined in the software include: different types of bridge rails, crash cushions, guardrails, median barriers, pole, tree, sign, special edges, and terminal ends.

Alternatives

ROADSIDE FEATURES FOR ALTERNATIVE NUMBER:									1
ALTERNATIVE NAME							DEFAULT X-SECTION		
CONSTRUCTION COST					ANNUAL MAINTENANCE COST				
GENERAL HAZARD TYPE	SPECIFIC HAZARD TYPE	START STATION	START SIDE	START OFFSET	END STATION	END SIDE	END OFFSET	PARAMETER	VALUE
		STATIONS		ft	STATIONS		ft		
BridgeRails	GenericBR							Width (in.)	12
BridgeRails	TL2LowProfileBR							Width (in.)	12
BridgeRails	TL3+FShapeBR							Width (in.)	12
BridgeRails	TL3+NJShapeBR							Width (in.)	12
BridgeRails	TL3+SingleSlpBR							Width (in.)	12
BridgeRails	TL3+VertWallBR							Width (in.)	12
BridgeRails	TL3FShapeBR							Width (in.)	12
BridgeRails	TL3NJShapeBR							Width (in.)	12

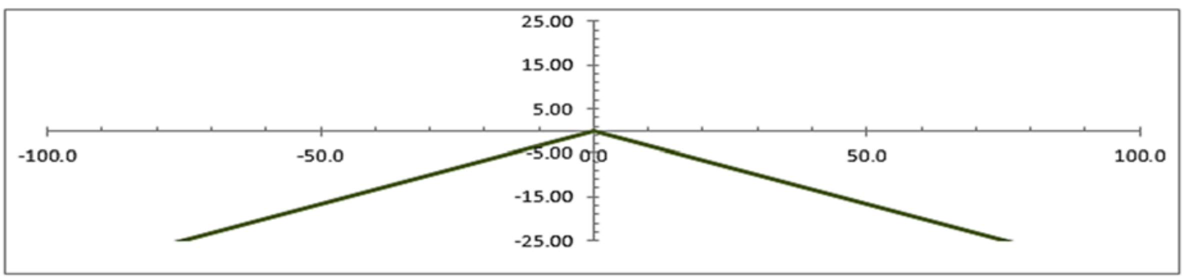
Figure 16. RSAPv3 Alternatives Tab

4.1.2.5 Cross-Section Information

Figure 17 is the cross-section window where the user can create the desired cross-sections or the predefined cross-sections for the segmented project. Figure 18 shows how the cross-sections can be edited.

			ALTERNATIVES				
	DEFAULT X-SECTION		1 in 1	1 in 2	1 in 3	1 in 4	1 in 6
SEG	START STA	END STA	1	2	3	4	5
1	0+00.	0+20.00	1 in 1	1 in 2	1 in 3	1 in 4	1 in 6

Figure 17. RSAPv3 Cross-Sections Assigning to Alternatives



Name	All 3:1							
	Primary Roadside Profile							
	Shoulder							
Slope Width	0.0 ft	0 ft	0 ft	0 ft	0 ft	0 ft	100 ft	
Slope	-50 H:1V	H:1V	H:1V	H:1V	H:1V	H:1V	-3 H:1V	
Offset	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Elev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-33.33

	Median Profile							
	Shoulder						Shoulder	
Slope Width	0 ft	0 ft	0 ft	0 ft	0 ft	0 ft	0 ft	
% Clr Med Width		50%	0%	0%	0%	50%		
Slope	50 H:1V	3 H:1V	H:1V	H:1V	H:1V	-3 H:1V	-200 H:1V	
Offset	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Opposing Roadside Profile							
	Shoulder							
Slope Width	0.0 ft	0 ft	0 ft	0 ft	0 ft	0 ft	100 ft	
Slope	-50 H:1V	H:1V	H:1V	H:1V	H:1V	H:1V	-3 H:1V	
Offset	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-100.0
Elev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-33.33

Figure 18. RSAPv3 Cross-Section Editing Tool

4.1.2.6 Miscellaneous Information

RSAPv3 has an analysis tool in which the user can adjust the minimum and maximum number of trajectories that can be selected from the following data: encroachment rate, warrant tool, and other information as shown in Figure 19.

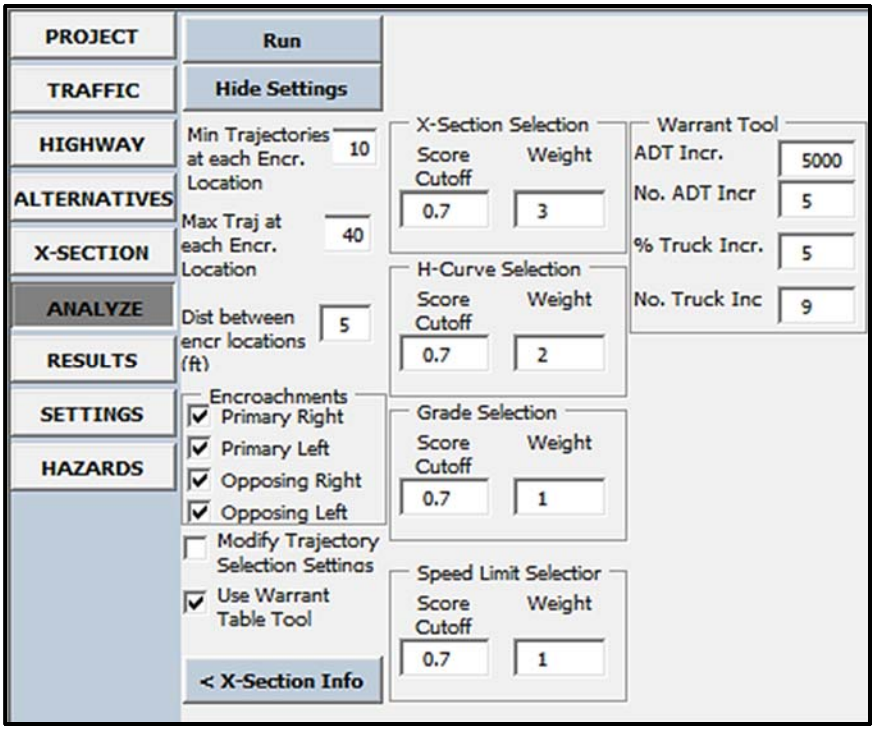


Figure 19. RSAPv3 Analysis Tool

After choosing the ‘Run’ button, the analysis will start and then the benefit-cost report, segment report, feature report and warrant report will be displayed for the project.

4.2 Selection of Input Data

For this research, four alternatives were selected to determine the best cost-effective countermeasure for different geometric and traffic conditions. Both versions of RSAP (RSAPv2 and RSAPv3) were used to determine the differences between outputs. The following are the four alternatives checked in every run performed in this research.

1. Do nothing (assumes a 1:1 foreslope)

2. Flattening the foreslope to 1:3

3. Flattening the foreslope to 1:6

4. Installing the guardrail

And these conditions were tested for different design speeds, different AADTs and different fill heights.

AADTs – 250 vpd, 500 vpd, 750 vpd, 1000 vpd and 1500 vpd

Design Speeds – 45 mph, 55 mph, 60 mph, 65 mph and 70 mph

Fill Heights – 1 ft., 7 ft., 13ft. and 20 ft.

Roadway Type – Rural undivided two-lane

Lane Widths – 10 ft., 11 ft., and 12 ft.

Shoulder – 2 ft., 4 ft., and 6 ft.

Every combination of these six conditions was tested with four different alternatives specified above. One thousand two hundred runs in each RSAP version were needed for the analysis.

Table 4. Input Data

AADT (vpd)	Design Speed (mph)	Fill Height (ft.)	Shoulder (ft.)	Lane Width (ft.)
250	45	1	2	10
500	55	7	4	11
750	60	13	6	12
1000	65	20		
1500	70			

Procedure Involved

Step 1: Determine all possible inputs and tabulate

Step 2: Determine the installation cost for every alternative and for every roadway condition

Step 3: Develop cross-sections for every alternative in every run

Step 3: Input all the values in the software and run the analysis in both versions

Step 4: Tabulate all benefit-cost ratios

Step 5: Develop decision matrices

Input parameters were selected as given in Table 4. The procedure followed for calculating the installation costs for every run is mentioned in Appendix B.

4.3 Application of Software for the Selected Input Data

In order to identify the difference between results from both the versions of RSAP, the identical input values were given in both versions, but with a different procedure as explained in previous sections. The sequence of steps involved for running the software in each version is explained in Appendix C by taking the below example. The procedure for calculating the installation cost for every condition is explained in Appendix B. The installation costs for each alternative can be found from Table 11, Table 15, and Table 20.

An Example to Explain the Application of the Software in Both Versions of RSAP

To determine the cost-effectiveness countermeasures among the selected alternatives, the input data selected in one of the runs are listed below.

AADT: 500 vpd

Design Speed: 45 mph

Fill Height: 1 ft.

Shoulder Width: 2 ft.

Lane Width: 10 ft.

Segment Length: 2000 ft. (Tangent Segment)

Life: 25 years; and

Discount rate: 4 Percent

Installation costs for the alternatives were:

Alternative 1: Do nothing (1:1 foreslope), $0;

Alternative 2: Improving to 1:3 foreslope, $7,010;

Alternative 3: Improving to 1:6 foreslope, $9,283; and

Alternative 4: Installing a guardrail, $100,450.

The procedure involved for running the software in both versions for the above example is illustrated in Appendix C by figures of sequential user interface windows which appear for both versions.

The results (benefit-cost ratio table) for each performed run are given in Appendix D. The interpretation of benefit-cost ratio table for the above example is given in Chapter 5. The overall analysis of the results for all the performed runs in both versions is also explained in Chapter 5.

CHAPTER 5. ANALYSIS AND RESULTS

The primary roadside safety features of this study are foreslope and guardrail. The procedure given in Appendix C was followed to input the selected parameters in both versions of RSAP. The benefit-cost ratio table was the main focus of the results. Cost-effectiveness alternatives were developed from each benefit-cost ratio table for every geometric and traffic condition. The interpretation of benefit-cost ratio table is given below by taking the example given in Chapter 4.

5.1 Selecting Cost-Effective Option from Benefit-Cost Ratio Table

The benefit-cost ratio table using RSAP for the example explained in Chapter 4, given the following input parameters, is shown in Figure 20.

Input Parameters

AADT: 500 vpd

Design Speed: 45 mph

Fill Height: 1 ft.

Shoulder Width: 2 ft.

Lane Width: 10 ft.

Segment Length: 2000 ft. (tangent segment)

Life: 25 years; and

Discount rate: 4 percent.

Installation costs for the alternatives were:

Alternative 1: Do nothing (1:1 foreslope), $0;

Alternative 2: Improving to 1:3 foreslope, $7010;

Alternative 3: Improving to 1:6 foreslope, $9283; and

Alternative 4: Installing a guardrail, $100,450.

5.1.1 Benefit-Cost Ratio Table Interpretation (RSAPv2)

File Name: AADT500DS45H1
Project Description: AADT500DS45H1

Alternative	Description
1	1:1
2	1:3
3	1:6
4	Guardrail

	Alternative			
Alternative	1	2	3	4
1	0.00	8.20	8.64	-0.10
2	0.00	0.00	10.14	-0.65
3	0.00	0.00	0.00	-0.86
4	0.00	0.00	0.00	0.00

Figure 20. Benefit-Cost Ratio Table (RSAPv2) for AADT 500 DS 45 H1

Beginning with alternative 4 (Installation of Guardrail), the benefit-cost ratios are all negative. Alternative 4 is the most expensive alternative and can be expected to be the safest one. But for this particular condition, RSAPv2 predicted that the vehicles' crash costs when they hit a guardrail were greater than vehicles' crash costs when they leave the roadway on any given foreslopes. Therefore, alternative 4 is not the cost-effective alternative for this particular condition. Alternative 3 has a benefit-cost ratio of 8.64 over alternative 1, and 10.14 over alternative 2, which implies alternative 3 is the cost-effective option over alternative 2 and alternative 1. The cost-effective option for the entire run can be decided as alternative 3 at this point because alternative 4 was found to be not cost-beneficial over any of the alternatives and alternative 3 is cost-beneficial over alternative 2 and alternative 1. Considering alternative 2, it has a benefit-cost ratio of 8.20 over alternative 1, which implies alternative 2 is the cost-effective option over alternative 1. Since alternative 3 is the cost-effective option over alternative 2, alternative 3 is determined to be the cost-effective option for this run. Therefore, upgrading to a 1:6 foreslope would provide the most benefit (i.e., safety improvements) for the cost (i.e., funds spent on construction) and for the chosen input parameters.

5.1.2 Benefit-Cost Ratio Table Interpretation (RSAPv3)

			Decision Point Benefit-Cost Ratio:				1
			Alternative Choice				
With Respect to Alternative			1	2	3	4	
		ALTERNATIVES	Foreslope (1:1)	1:3	1:6	Guardrail	
	1	Foreslope (1:1)	1.00	-0.33	-1.28	-0.70	
	2	1:3		0.00	-4.53	-0.72	
	3	1:6			0.00	-0.65	
	4	Guardrail				0.00	

Best Choice is: **Foreslope (1:1)**

Figure 21. Benefit-Cost Ratio Table (RSAPv3) for AADT 500 DS 45 H1

Every alternative in the benefit-cost ratio table shown in Figure 21 shows a negative value. Even though the same input parameters were given as in RSAPv2, the benefit-cost ratios are different in RSAPv3. By definition, this would mean that RSAPv3 calculated these alternatives as either providing a negative cost value for the improvement or providing an increased crash cost for the improvement relative to the original condition. The negative ratios continued to appear in subsequent runs. Neither of these possibilities agrees with the commonly-accepted understating of roadside improvements. A clear explanation regarding the results of RSAPv3 is discussed in the next section.

5.2 Results of RSAPv3

As discussed in the previous section, specific negative benefit-cost values were observed in every run using RSAPv3. RSAPv3 was run for 10 ft. width lanes and 2 ft. shoulders for all the AADTs and design speeds.

The input parameters AADT, design speed, length of segment, life of project, crash cost, shoulder width, fill height, and all the combination of these values were tested for extreme values from low range to high range to check for any difference in input. But the benefit-cost ratios were still impractical. Installation costs were also checked for low range values to high range values, but the unusual results remained. By contrast, the results from the same analysis in RSAPv2 provided positive benefit-cost values. In an attempt to determine the reason for impractical results, the cross-section tool was also checked. It was found out that the RSAPv3 predicted a higher crash rates if the foreslopes are flattened. For example, it calculated a higher crash rate for 1:6 foreslopes than a 1:3 foreslopes, which is contrary to conventional wisdom. An example is clearly explained below to show the benefit-cost ratio table of RSAPv3 for flattening foreslopes.

Input Parameters for the Example

AADT: 500 vpd

Design Speed: 60 mph

Highway Type: Rural Undivided Two-lane

Segment Length: 2000 ft. Tangent Segment

Lane Width: 10 ft.

Shoulder Width: 2ft.

Fill Height: 7 ft.

Alternatives

Alternative 1: Do nothing (1:1 foreslope), $0;

Alternative 2: Improving to 1:3 Foreslope, $55, 830; and

Alternative 3: Improving to 1:6 Foreslope, $97,120

The cross-sections given for all the alternatives are as shown in Figure 22.

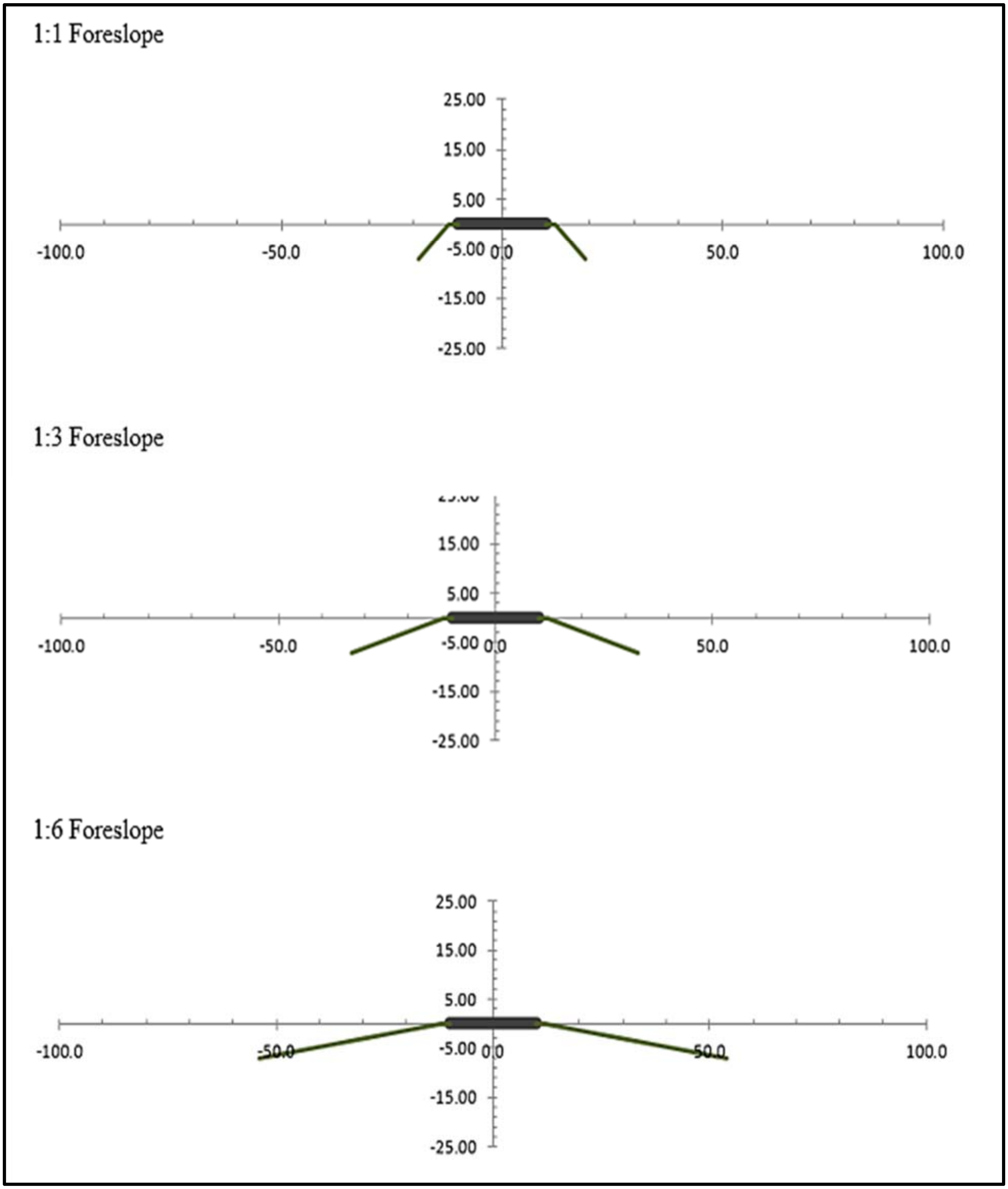


Figure 22. Cross-Sections for Three Alternatives

Benefit-Cost Ratio Table

Decision Point Benefit-Cost Ratio: 1

With Respect to Alternative		ALTERNATIVES	Alternative Choice: 1 Foreslope (1:1)	2 1:3	3 1:6		
	1	Foreslope (1:1)	1.00	-0.16	-0.11		
	2	1:3		0.00	-0.05		
	3	1:6			0.00		

Best Choice is: Foreslope (1:1)

Figure 23. Benefit-Cost Ratio Table for the Above Example

The benefit-cost ratios are all negative values. The negative values indicates that 1:3 foreslope and 1:6 foreslope would have more crash rate than 1:1 foreslope, which is contrary to engineering judgement. Flatter foreslopes provides a better environment for the encroached vehicles to merge back onto the road, but the results in Figure 23 indicate that there is a higher crash rate at a flatter foreslope than on a steeper foreslope.

5.3 Results of RSAPv2

Because of the limitation from RSAPv3, RSAPv2 was continued to be used for the analysis in this research and it was run for every specified input values. Benefit-cost ratios for every run were tabulated and presented in Appendix D. RSAPv2 was run for all the AADTs, design speeds, fill heights, shoulder widths and for all 10 ft. width lanes. The lane widths 10 ft., 11 ft., and 12 ft. were considered for this research, but the benefit-cost ratios differed only slightly, which states that the cost-effective option for every run remained same, but with little difference in the benefit-cost ratio as shown in tables 5 to 7. This example is presented to explain the difference in benefit-cost ratios for varying lane widths.

Example

Table 5. AADT 750 DS 55 H7, Shoulder 2 ft., and Lane width 10 ft.

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.17	6.62	3.64
1:3	0.00	0.00	3.18	-1.16
1:6	0.00	0.00	0.00	-8.95
Guardrail	0.00	0.00	0.00	0.00

Table 6. AADT 750 DS 55 H7, Shoulder 2 ft., and Lane width 11 ft.

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.96	6.47	3.56
1:3	0.00	0.00	3.11	-1.14
1:6	0.00	0.00	0.00	-8.75
Guardrail	0.00	0.00	0.00	0.00

Table 7. AADT 750 DS 55 H7, Shoulder 2 ft., and Lane width 12 ft.

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.77	6.34	3.46
1:3	0.00	0.00	3.04	-1.11
1:6	0.00	0.00	0.00	-8.55
Guardrail	0.00	0.00	0.00	0.00

Since there were only small changes in the benefit-cost results for the differences in lane widths, all the runs were performed for 10 ft. lanes and the figures developed were recommended for 10 ft. to 12 ft. lanes, because the benefit-cost alternative remained the same for varying lane widths.

Results Considered

Given these differences in output, it is recommended that RSAPv2 continue to be used for analysis as it seems to provide more consistent and practically accepted results. All the benefit-cost ratios of RSAPv2 are shown in Appendix D from Table 21 to Table 56. The alternatives for each run are given in a sequence from least expensive alternative to most expensive alternative. At fill heights of 1 ft. and 7ft., installing the guardrail is the most expensive alternative of the four alternatives. Therefore, in these cases (at fill heights of 1ft. and 7 ft.) installing guardrail is the fourth alternative. At fill heights of 13ft. and 20ft. the cost of flattening the foreslope to 1:3 and 1:6 increases and guardrail becomes the second most expensive alternative among the four alternatives. Therefore, in these cases (at fill heights of 13 ft. and 20ft.) installing guard rail is the second alternative. Table 21 to Table 26; Table 33 to Table 38; and Table 45 to Table 50 represent the benefit-cost ratio tables of 1ft. and 7ft. fill heights. Therefore, in these tables installing the guardrail is the fourth alternative. Table 27 to Table 32; Table 39 to Table 44; and Table 51 to Table 56 represent the benefit-cost ratio tables of 13ft. and 20ft. fill heights. Therefore, in these tables installing the guardrail is the second alternative. For completeness, benefit-cost ratios of executed RSAPv3 runs were also shown in Appendix D.

5.4 Figures Developed Based on Results of RSAPv2

As discussed, results of RSAPv2 were considered for developing the figures showing the benefit-cost results of possible roadside improvements. Figures were divided into two sets, the first set where benefit-cost ratios greater than 1 were considered beneficial. The other set, where benefit-cost ratios greater than 5 were considered the minimum to be beneficial. Each set was divided into three parts with varying shoulder widths 2 ft., 4 ft., and 6 ft., each including lane widths of 10 ft. to 12 ft., every fill height, AADT and all design speeds considered for this research. Developed figures were presented in Section 5.5 where the benefit-cost alternative can be selected with a benefit-cost limit value either 1 or 5.

5.5 Figures Developed

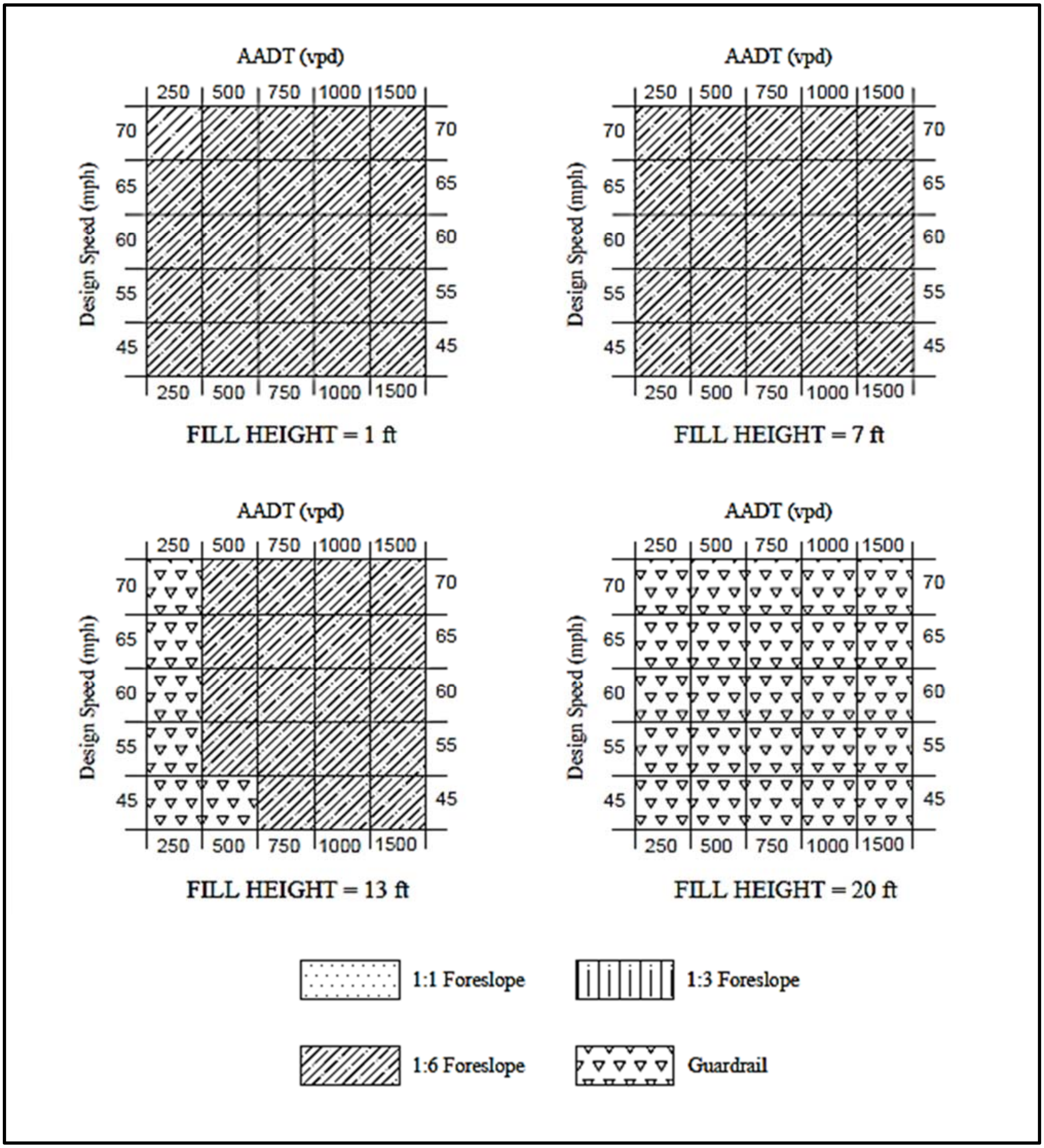


Figure 24. Lane Widths 10 to 12 ft.; Shoulder Width 2 ft.; Benefit-Cost >1

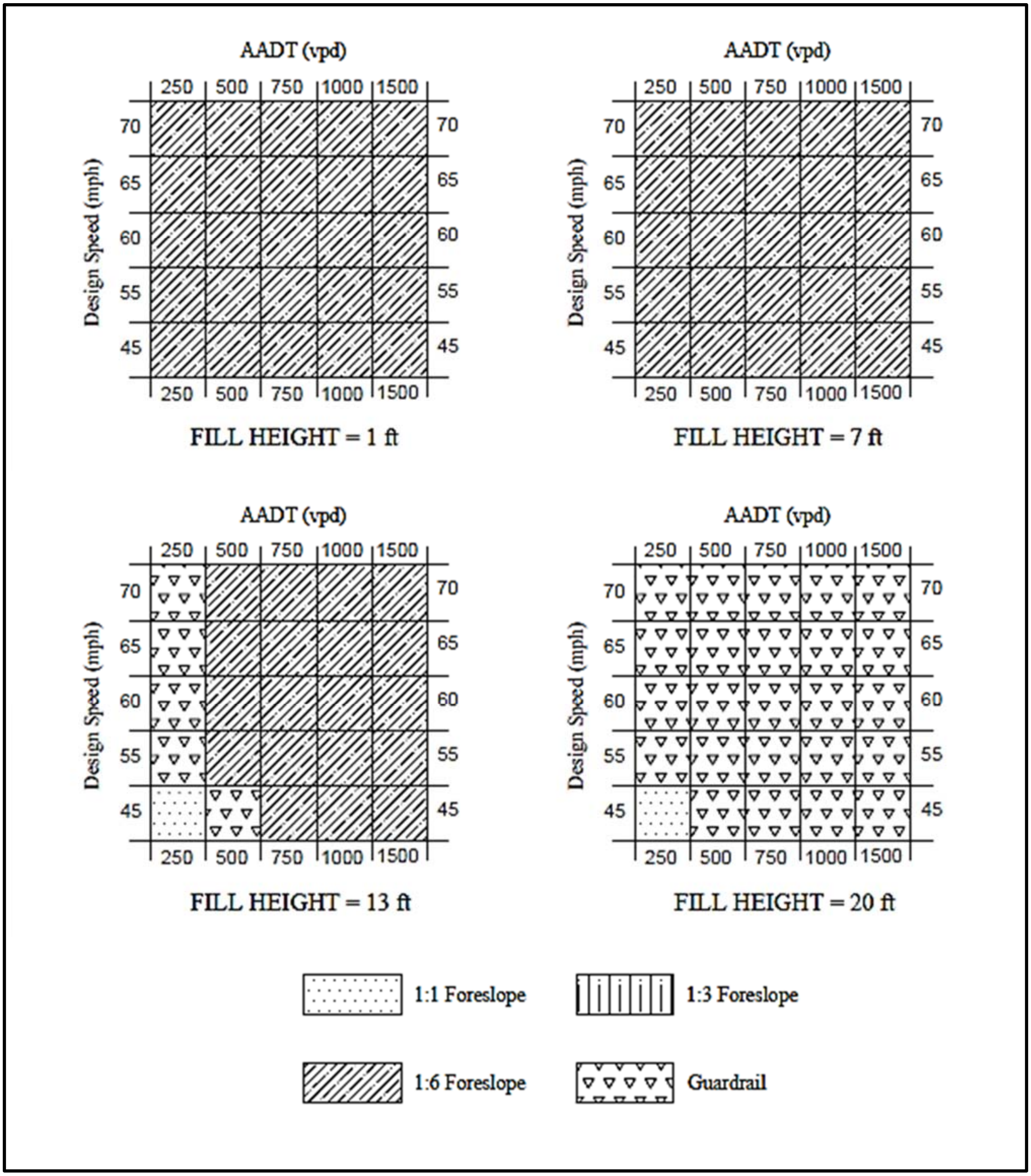


Figure 25. Lane Widths 10 to 12 ft.; Shoulder Width 4 ft.; Benefit-Cost >1

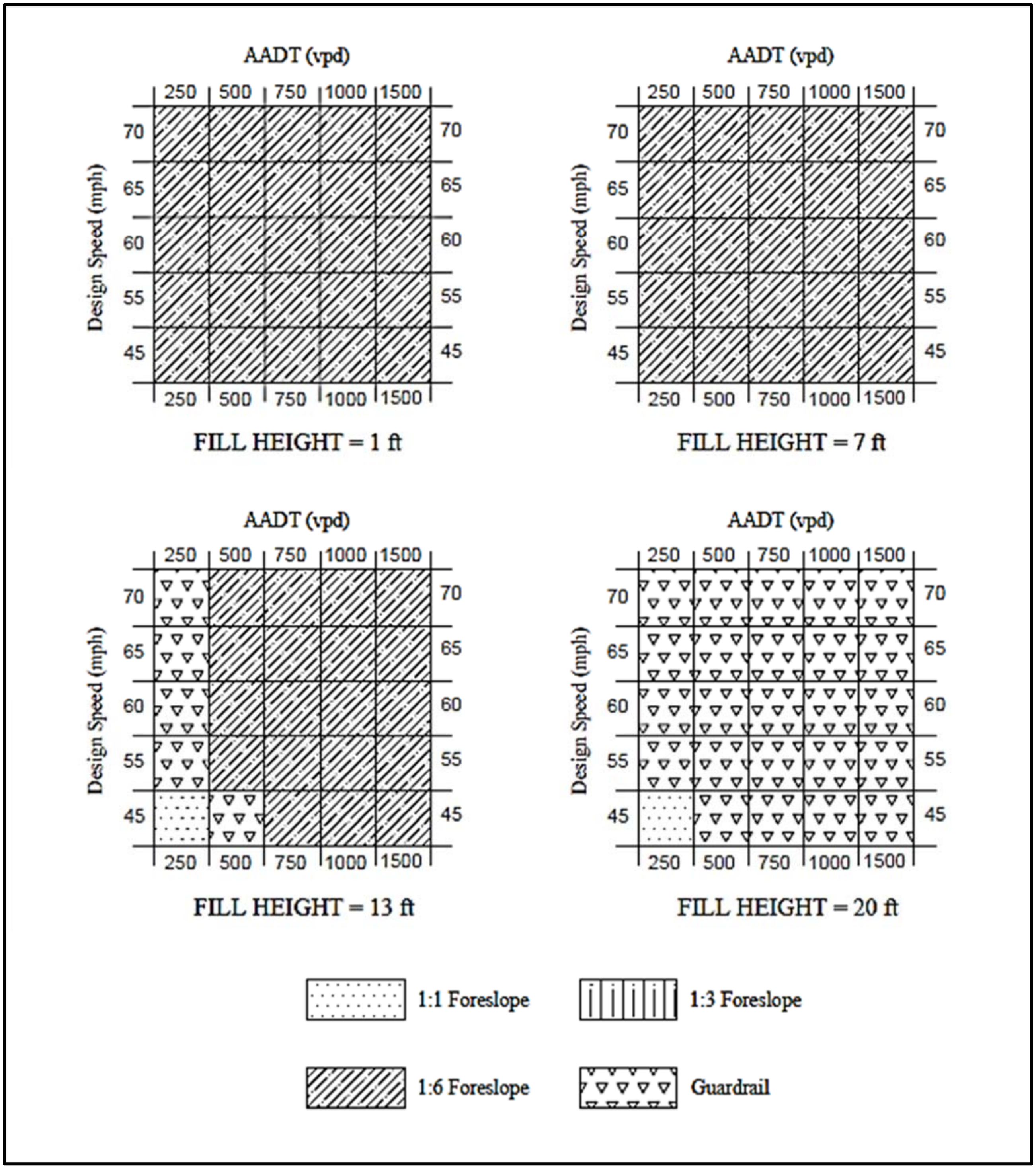


Figure 26. Lane Widths 10 to 12 ft.; Shoulder Width 6 ft.; Benefit-Cost >1

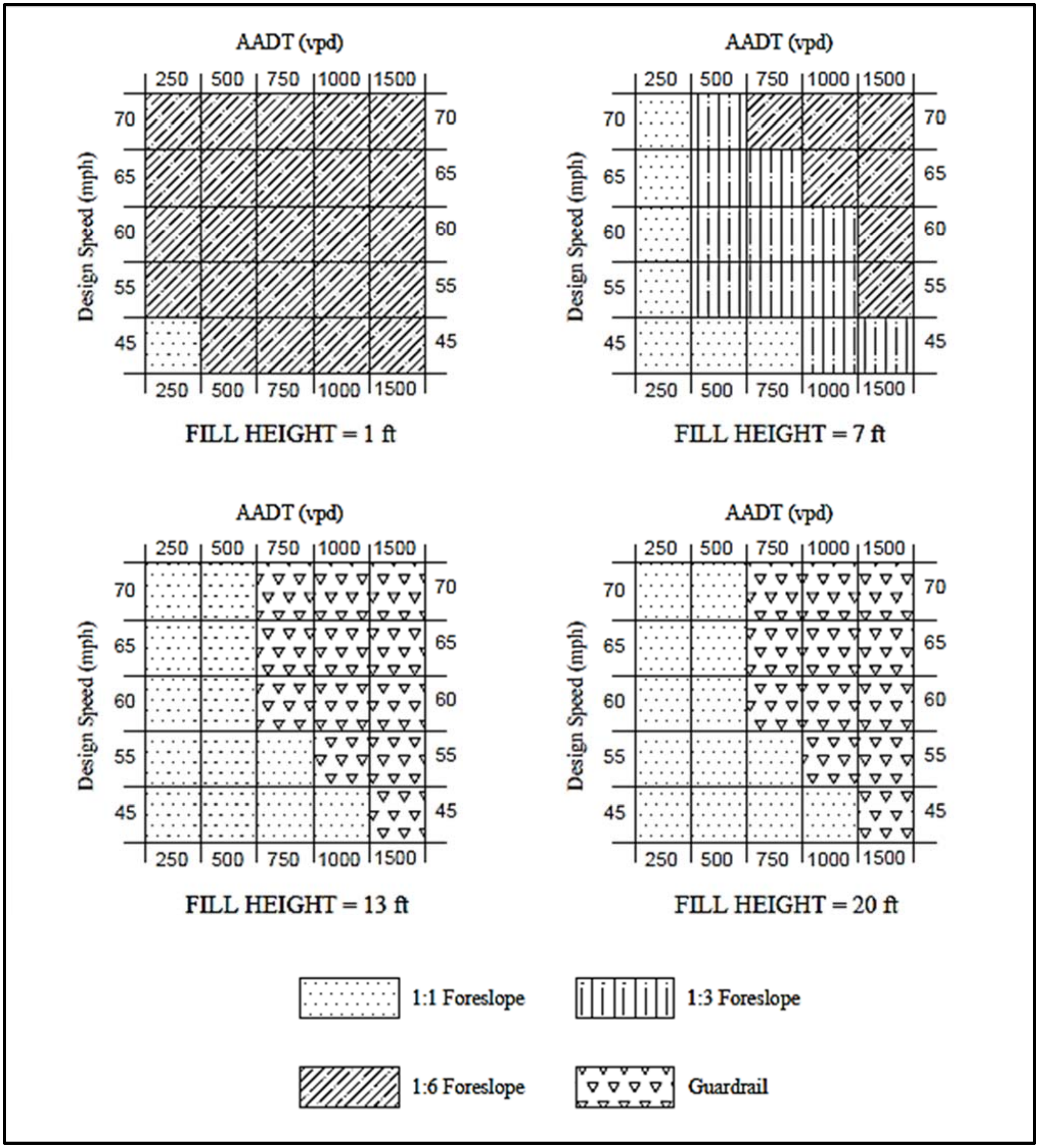


Figure 27. Lane Widths 10 to 12 ft.; Shoulder Width 2 ft.; Benefit-Cost >5

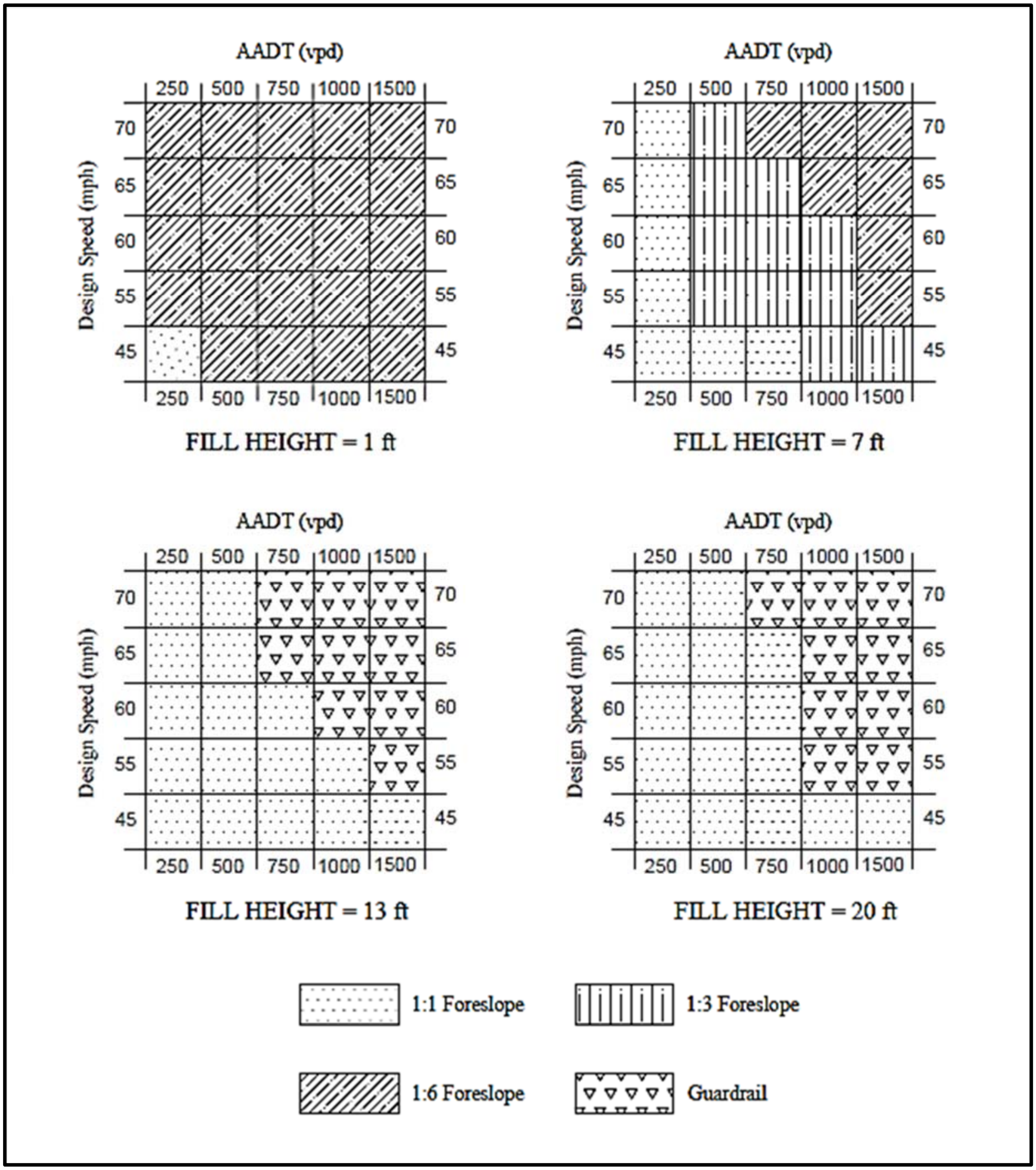


Figure 28. Lane Widths 10 to 12 ft.; Shoulder Width 4 ft.; Benefit-Cost >5

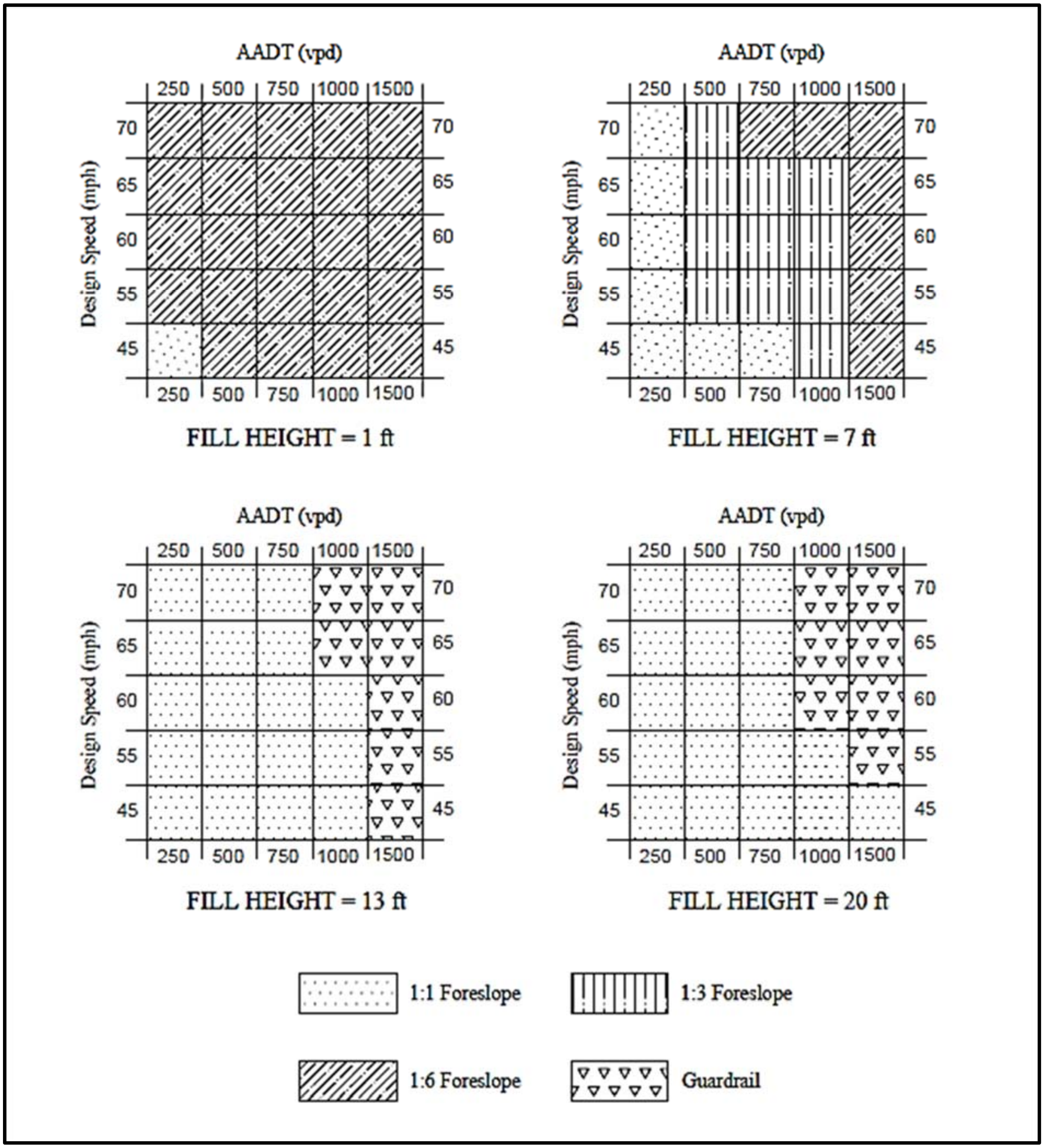


Figure 29. Lane Widths 10 to 12 ft.; Shoulder Width 6 ft.; Benefit-Cost >5

5.6 Interpretation of Figures

The cost-effective alternatives for lane width 10 ft., shoulder width 6ft., and fill height 7ft. (benefit-cost >5) can be found from the matrix of fill height 7 ft. (top right corner) in Figure 29. The particular matrix is again shown in Figure 30 to clearly explain the interpretation of each individual element.

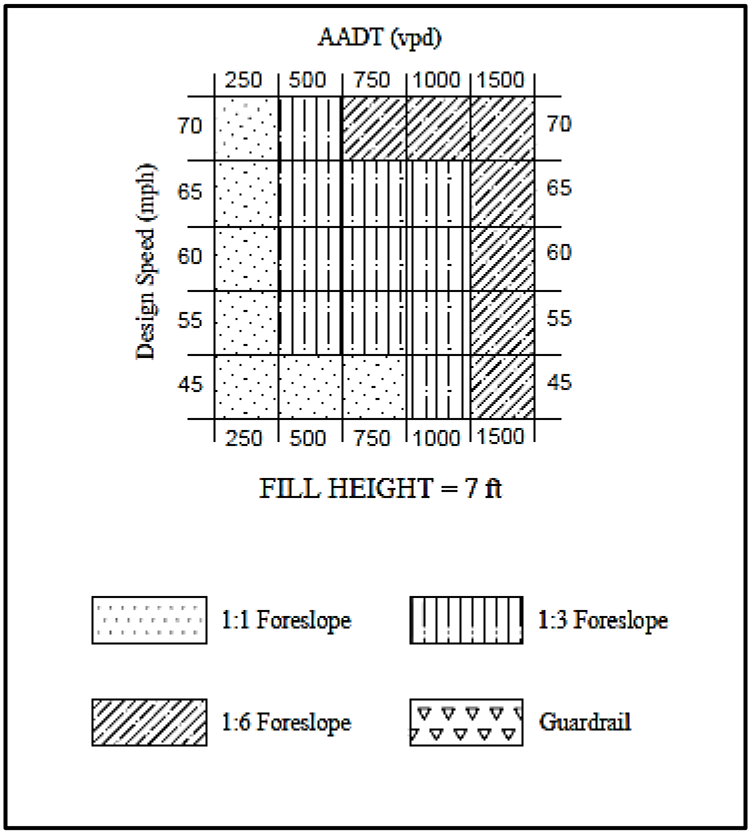


Figure 30. Recommended Figure for Lane width 10 ft., Shoulder width 6ft., and Fill Height 7ft. (Benefit-Cost >5)

1:1 Foreslope:

AADT 250 vpd – Design Speeds 45 mph, 55 mph, 60 mph, 65 mph, and 70 mph; and
AADT 500 vpd and 750 vpd – Design Speed 45 mph

For the above conditions the figure does not recommend any upgrade but to stay at 1:1 foreslope if the threshold benefit-cost ratio is greater than 5. It is because at lower AADT and lower speeds, there are fewer actual crashes when compared to higher AADTs and higher design speeds. Therefore for the low estimated crash cost for these conditions, the estimated benefits (i.e., safety improvements) are not high enough to justify the cost (i.e., funds spent to upgrade).

1:3 Foreslope:

AADT 500 vpd – Design Speeds 55 mph, 60 mph, 65 mph, and 70 mph;
AADT 750 vpd – Design Speeds 55 mph, 60 mph, and 65 mph; and
AADT 1000 vpd – Design Speeds 45 mph, 55 mph, 60 mph and 65 mph

For these conditions the figure recommends upgrading to a 1:3 foreslope or to stay at a 1:3 foreslope, if the threshold benefit-cost ratio is greater than 5. These are higher AADTs and design speeds compared to the previous conditions. Therefore, for the estimated crash rate, there are enough benefits (crashes avoided) from upgrading to 1:3 foreslope to justify the upgrade costs (i.e., funds spent on upgrading to 1:3).

1:6 Foreslope:

AADT 750 vpd and 1000 vpd – Design Speed 70 mph; and
AADT 1500 vpd – Design Speeds 45 mph, 55 mph, 60 mph, 65 mph, and 70 mph

For these conditions the figures recommend upgrading to a 1:6 foreslope or to stay at a 1:6 foreslope, if the threshold benefit-cost ratio is greater than 5. Therefore, for the estimated crash rate, it is beneficial to upgrade to a 1:6 foreslope for the cost (i.e., funds spent on upgrading to 1:6).

Guardrail:

For these particular geometric conditions the figures do not recommend installing guardrail as a cost-effective alternative for any AADT and design speed.

Figures were developed in a way that one can easily determine the cost-effective alternative for a range of AADTs, design speeds, fill heights, lane widths, and shoulder widths that were considered in this research. Noticeable points from the developed figures and future recommendations for software exploration are given in Chapter 6.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

This research concentrated on examining the roadside countermeasures on rural roads. Flattening the foreslope to 1:3, flattening the foreslope to 1:6 and installing the guardrail were the countermeasures considered. Different geometric and traffic conditions were taken to analyze the countermeasures. Identical conditions were analyzed in both versions to compare the results. The results from RSAPv2 were tabulated where one could look at the table of specific road conditions and can decide if a cost-effective countermeasure exists for their specific conditions. The simplified figures were developed from all the benefit-cost ratios so that a local official can determine the cost-effective alternative among the four specified alternatives for specific geometric and traffic conditions without going through all the benefit-cost analysis themselves.

Both RSAPv2 and RSAPv3 are the tools which can be used to evaluate the benefit-cost ratios of roadside features or hazards. Both versions have their own benefits and drawbacks. For example, RSAPv2 is useful for simple projects where the complications in the roadway characteristics are kept to a minimum. Results of RSAPv2 also can be easily interpreted. RSAPv2 seems best used when projects include only a limited number of pre-defined roadside features. RSAPv3 is the latest version of the software and includes more options for inputting detailed alternatives for any project scenario. Almost all roadside hazards are preloaded into the software with varying specifications. However, for the analysis conducted for this research, RSAPv3 provided results with negative benefit-cost results for roadside improvements which were counterintuitive. For this reason, only RSAPv2 results were used for this analysis.

6.1 Highlights from the Developed Figures

- Flattening the foreslope to 1:6 was determined to be the cost-effective alternative at any traffic condition, at fill heights are from 1 ft. and 7 ft. and for every shoulder width and lane width considered when a benefit-cost >1.
- Installing the guardrail is the cost-effective alternative when the fill height is 20 ft. and when the benefit-cost >1 except in conditions where AADT and design speed are 250 vpd and 45 mph, respectively, with 4 ft. and 6 ft. shoulders.

- When the benefit-cost >1, ‘ Do Nothing’ is the cost-effective option, only when the AADT and design speed are 250 vpd and 45 mph with 13 ft. and 20 ft. fill heights and 4ft. and 6ft. shoulder widths, respectively.
- When the benefit-cost >5, and at fill height 1 ft., a 1:6 slope is the cost-effective option except where ‘Do Nothing’ is the cost-effective option for AADT and design speed 250 vpd and 45 mph, respectively.
- Considering all the figures developed, a 1:3 slope appeared to be the cost-effective alternative only at 7 ft. fill height and at only specific traffic conditions using a benefit-cost either greater than 1 or greater than 5.
- When the benefit-cost >5, installing Guardrail and ‘Do Nothing’ are the only cost-effective alternatives with fill heights 13 ft. and 20 ft.

6.2 Recommendations and Areas of Future Research

There are several areas that were considered useful for additional research:

- RSAPv3 provided unexpected results in this study and so was not used in the final analysis. More research into how RSAPv3 determines its results in analyzing the foreslopes would help understand how best to use this version.
- Rural highways will serve as suburban roadways as cities grow. Therefore, exploring design speeds like 35 mph and 40 mph on rural highways for different roadside alternatives would be a conservative approach.
- One of the roadside feature that affects the lateral encroachment crash rate is clear-zone. Increasing the clear-zone width could be examined to determine the cost-effectiveness for various increase in widths.
- This research only examined foreslopes and installing guardrail. A logical extension of this research would be to explore backslope, parallel ditch scenarios, intersecting slopes, fixed objects, culvert ends, different longitudinal barriers, and different terminals and crash cushions.

REFERENCES

1. U.S Department of Transportation, Federal Highway Administration. Roadway Departure Safety. http://safety.fhwa.dot.gov/roadway_dept/, Accessed December 20, 2016.
2. *Roadside Design Guide*. American Association of State Highway and Transportation Officials. Washington D.C., 2011.
3. Hutchinson J.W. and T.W. Kennedy. Medians of Divided Highways-Frequency and Nature of Vehicle Encroachments. Engineering Experiment Station Bulletin 487, University of Illinois, Champaign, Illinois, 1996.
4. Mak K.K. Safety Effects of Roadside Design Decisions-Roadside. In *Transportation Research Record: Journal of the Transportation Board, No. 1512*, Transportation Research Board of the National Academies, Washington D.C., 1995, pp. 16-21.
5. Lee J. and F. Mannering. Analysis of Roadside Accident Frequency and Severity and Roadside Safety Management. Final Research Report WA-RD 475.1. Washington State Transportation Center (TRAC). Washington Department of Transportation, Olympia, Washington, 1999.
6. Zegeer C.V. and F.M. Council. Safety Relationships Associated with Cross-Sectional Roadway Elements. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1512*, Transportation Research Board of the National Academies, Washington D.C., 1995, pp. 29-36.
7. Miaou, S.P. Estimating Roadside Encroachment Rates With the Combined Strengths of Accident and Encroachment-Based Approaches. Final Report FHWA-RD-01-124. Federal Highway Administration, Mclean, Virginia, 1996.
8. Wu Q., G. Zhang, X. Zhu, X.C. Liu, and R. Tarefder. Analysis of Driver Injury Severity in Single-Vehicle Crashes on Rural and Urban Roadways. *Journal of Procedia - Accident Analysis and Prevention*, Vol. 94, 2016, pp. 35-45.
9. Rys M.J. and E.R. Russell. Use of Guardrail on Low-Volume Roads According to Safety and Cost Effectiveness. Final Report K-TRAN: KSU-96-06. Kansas Department of Transportation, Topeka, Kansas, 1997.

10. Mak K.K. and D.L Sicking. *Roadside Safety Analysis Program (RSAP) – Engineer's Manual*, National Cooperative Highway Research Program Report No. 492, Transportation Research Board, Washington D.C., 2003.
11. Mak K.K. and D.L Sicking. *Roadside Safety Analysis Program (RSAP) – User's Manual*, *Improved Procedures for Cost-effectiveness Analysis of Roadside Safety Features*. National Cooperative Highway Research Program Project 22-9, Transportation Research Board, Washington D.C., 2002.
12. Ray, M.H., C.E. Carrigan, C.A. Plaxico, S-P Miaou, and T.O. Johnson. Roadside Safety Analysis Program (RSAP) Update. National Cooperative Highway Research Program Project 22-27, Transportation Research Board, Washington D.C., 2012.
13. Schrum, K.D., F.D.B. Albuquerque, D.L. Sicking, R.K. Faller, and J.D. Reid. Roadside Grading Guidance-Phase II. Report No. TRP-03-269-14. Wisconsin Department of Transportation, Madison, Wisconsin, 2014.
14. Schrum, K.D., K.A. Lechtenberg, C.S. Stolle, R.K. Faller, and D.L.Sicking. Cost-Effective Safety Treatment for Low-Volume Roads. Report No. TRP-03-222-12. Nebraska Department of Roads, Lincoln, Nebraska, 2012.
15. Ray M.H. and C.E Carrigan. Methodology for Systematically Comparing Longitudinal Barrier Performance. Transportation Research Board 93rd Annual Meeting Compendium of Papers. Transportation Research Board, Washington D.C., 2014.
16. Appiah J. and B.H. Cottrell. A Simplified Tool for Benefit-Cost Analysis of Guardrail Needs for Two-Lane, Low-Volume Roads. Report No. FHWA/VTRC 16-R5. Virginia Department of Transportation, Richmond, Virginia, 2015.

APPENDIX A

Survey of Practice

Survey Responses

Alabama DOT

The Alabama (ALDOT) used RSAP for analyzing roadside features at the time of this survey. They have been using RSAPv2, but they are now slowly transitioning to RSAPv3. They have a standard process of using the RSAP software on rural roadside projects and analyzing the countermeasures with benefit-cost ratios. They found RSAPv3 better over RSAPv2 as RSAPv2 was not considered efficient for all the design speeds. They preferred RSAPv3 over RSAPv2 in analyzing concrete median barriers, but in analyzing rural roadside projects, ALDOT is still using RSAPv2 as it is considered to be a handy tool and less complicated.

Arizona DOT

The Arizona DOT uses the AASHTO Roadside Design Guide to analyze roadside safety features. Countermeasure benefit-cost ratios greater than 1 are considered acceptable for any type of project. The Arizona DOT uses RSAPv2 in analyzing the roadside features, but it is not the standard practice throughout the DOT. The projects which are more complicated are analyzed through the software, but not all of the projects have this done. The Arizona DOT uses RSAPv2 but was transitioning to RSAPv3 at the time of the survey. Mainly foreslope, backslope and intersecting slopes were analyzed using the software.

Arkansas State Highway and Transportation Department

The Arkansas State Highway and Transportation Department (ASHTD) did not use RSAP in analyzing the roadside hazards at the time of the survey. Using the Roadside Design Guide is the standard practice throughout the ASHTD. Benefit-cost ratios greater than 2 are considered acceptable for foreslope and culvert projects. Usually, the ASHTD extends culverts when there is evidence of a high number of crashes in the vicinity.

California DOT

The California DOT (Caltrans) used value analysis as an explicit road safety technique to improve the road safety, and the same is used for roadside safety at the time of the survey. Caltrans used RSAP only for a limited number of projects to find benefit-cost ratios for the different combination of AADTs, design speed, etc. They used both versions but had no specific reason or recommendation for using a particular version. RSAPv2 was identified as a useful tool for short tangent segments.

Connecticut DOT

The Connecticut DOT used their own Excel spreadsheets to determine the cost-effectiveness of roadway projects at the time of this survey. The same procedure was followed for roadside safety features. Benefit-cost ratios between 2 and 5 were considered acceptable and were used depending on the project importance and cost. In rural areas, the DOT opts for extending culverts mainly at locations where there are many crashes.

Florida DOT

Using RSAP was not the standard practice throughout the Florida DOT in analyzing the roadside features at the time of this survey. Roadside safety was reportedly analyzed using the Roadside Design Guide. They developed Excel sheets to determine the benefit-cost ratios for different countermeasures and different roadway conditions.

Illinois DOT

Illinois had a standard practice all over the DOT to use RSAP in analyzing roadside safety features at the time of this survey. They have used RSAPv2 for years and were also using RSAPv3, but not for all of the projects. Straight tangent segments were analyzed in RSAPv2, especially for foreslope, backslope, and culvert treatments. RSAPv3 was used for highways having high AADTs and with higher design speeds. Guardrail installation was considered to be more cost-effective for culverts at high-AADT locations; in rural areas the DOT usually opts to extend culverts only when there are frequent crashes.

Indiana DOT

Indiana also used RSAPv3 in analyzing the roadside safety features at the time of this survey, but it was not the standard practice throughout the DOT. They use the software mainly for determining cost-effective countermeasure options in median barriers. Foreslopes and culverts in rural areas were analyzed by the software and were considered acceptable when the benefit-cost ratio exceeded 1. RSAPv3 was also being used but only for a limited number of projects.

Maryland DOT

The Maryland DOT followed the Roadside Design Guide to analyze roadside features, and in addition, they used their own Excel spreadsheets to find the benefit-cost ratios of different countermeasures at the time of this survey. They also used crash modification factors from the Highway Safety Manual to analyze the roadside features in rural areas. They usually chose to extend a culvert when they observed a benefit-cost ratio greater than 2.

Massachusetts DOT

The Massachusetts DOT (MassDOT) used their own benefit-cost analysis program to analyze roadside features at the time of this survey. The DOT did not have a standard practice to follow in analyzing roadside safety features, but they followed the same process which is used for other road safety projects. Specifically, they depended on type and importance of a project to go for a particular benefit-cost ratio threshold. For zones with high crashes, benefit-cost ratios over 1 were found to be beneficial, bur for rural locations a threshold benefit-cost ratio of 2 was used.

Nebraska Department of Roads.

The Nebraska Department of Roads (NDOR) used RSAPv2 and RSAPv3 in analyzing the roadside features at the time of this survey. This was a standard practice throughout NDOR to determine the benefit-cost ratios for each potential countermeasure. NDOR used RSAPv2 for simple straight tangent sections, but with projects of high importance they RSAPv3. Generally, foreslope and culvert related projects in rural areas used RSAPv2 but with divided and high-volume roads they used RSAPv3.

Ohio DOT

The Ohio DOT used RSAPv2 in selecting the best countermeasure for roadside hazards at the time of this survey. This was not a standard practice throughout the DOT but they used RSAPv2 for determining cost-effective countermeasures for different roadway conditions. At areas with low AADT, they opted for the extension of culverts instead of installing guardrail. The Roadside Design Guide was mainly used to design the roadside features.

Oregon DOT

Oregon DOT used its own benefit-cost analysis program which consisted of Excel worksheets to analyze roadway departures at the time of this survey. They had never used RSAP when analyzing roadside features. Benefit-cost ratios found from Excel spreadsheets were used to analyze a countermeasure, where they considered threshold benefit-cost ratios above 2 to be beneficial depending on the project.

Texas DOT

Using the Roadside Design Guide was the standard practice throughout the Texas DOT (TxDOT) to determine cost-effective countermeasures at the time of this survey. RSAP was used, but this was not a standard practice. For foreslope flattening and culvert extension projects, they used their own Excel spreadsheets where they determined the benefit-cost ratios. Culvert extension was a typical safety improvement process followed on rural roads if it was considered a high-crash location.

Wisconsin DOT

The Wisconsin DOT (WisDOT) used RSAPv2 and was slowly transitioning to RSAPv3 at the time of this survey. They did not have a specific reason for using a particular version. They used RSAPv2 for straight tangent segments where there were no big changes in the roadway segment. RSAPv3 was used to determine the cost-effectiveness for the use of concrete median barriers. They also followed the Highway Safety Manual for roadside design by using crash modification factors.

Wyoming DOT

Wyoming has its own roadside design guide in which they had a ranking system to divide the road network into four sections at the time of this survey. They evaluated the cost-effectiveness on the highest 50 percent of the projects in each of the four network sections. Wyoming did use RSAP, but it was not a standard process for analyzing roadside features. The Wyoming DOT normally used FHWA worksheets from the Highway Safety Manual to determine this. They used threshold benefit-cost ratios greater than 1 generally (but not always) when analyzing a project, the benefit-cost was not used as the sole criteria for selecting alternatives.

APPENDIX B

Installation Costs

Procedure for Both Flattening the Foreslope and Installing the Guardrail

Installation Costs for Flattening the Foreslopes

The quantity needed for flattening the foreslopes to 1:3 and 1:6 is clearly explained by taking an example as shown in the Figure 31. In this example the original condition was assumed to have a 1:1 foreslope and a 7 ft. fill height. The procedure for calculating the amount of quantity (hatched portions) in the following sections. The hatched portions are the areas to be filled to flatten the foreslope. After the quantities are calculated, each quantity is multiplied by unit price to obtain the final price.

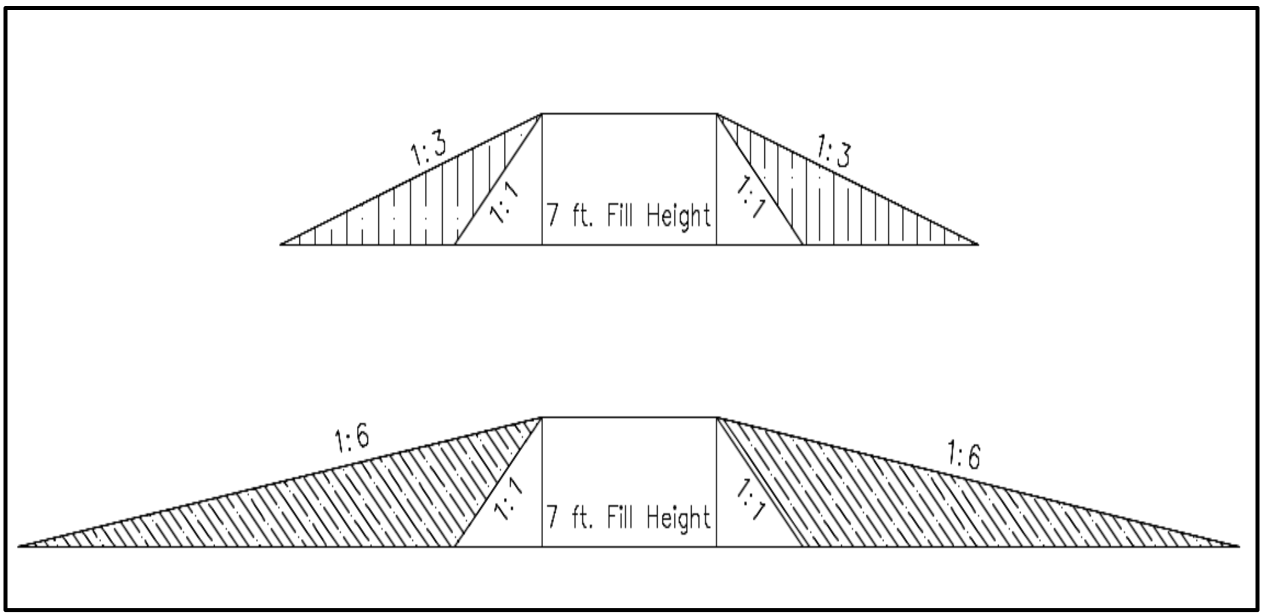


Figure 31. Quantity Needed to be Filled for Flattening the Foreslope to 1:3 and 1: 6 Foreslopes When There is an Existing 1:1 Foreslope

Flattening the Foreslope to 1:3

Table 8. Segment Characteristics

Segment Length (ft.)	2000
Fill Height (ft.)	1
Original Slope	1:1
Final Slope	1:3

Table 9. Area and Volume Calculations

Fill Area (sq. ft.)	1
Fill Volume (cu yd.)	74.1
Excavation Volume (cu yd.)	98.8
R/W Area (acre)	0.09
Seed Area (acre)	0.14

Fill area: The remaining portion of the 1:3 triangle with a base of 3 ft. and a height of 1 ft. when a 1:1 triangle with a base of 1 ft. and a height of 1 ft. is assumed to already be present, the area = ½' x 3' x 1' – ½' x 1' x 1' = 1 ft^2

Fill volume: 1 ft^2 area over 2,000 ft. length = 2,000/27 = 74. 1 yd.

Excavation Volume = 74.1 / 0.75 = 98.8 yd^3

Seed area = 3/1 * 2000 / 43560 = 0.14 acres

Right of way area = 2*2000/43560 = 0.09 acres

Table 10. Final Price Details

ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
Clearing and Grubbing	1	Lump Sum	$1,000.00	$1,000.00
Common Excavation (Contractor Furnished)	98.8	cu. yd.	$6.23	$616.00
Water (Grading) (Set)	1.0	Mgal	$35.00	$35.00
Compaction of Earth Work (Type AA) (MR 5-5)	74.1	Cu. Yd.	$1.90	$141.00
Field Office and Lab (Type C)	1	Each	$1,000.00	$1,000.00
Foundation Stabilization (Set)	1	Cu. Yd.	$50.00	$50.00
Contractor Construction Staking	1	Lump Sum	$800.00	$800.00
Mobilization (30 percent)	1			$1,093.00
ROAD TOTAL				$4,735.00
MISCELLANEOUS				
Seeding	0.14	Acre	$1,000.00	$140.00
Right of Way	0.09	Acre	$1,500.00	$135.00
Traffic control	2	Lump sum	$1,000.00	$2,000.00
TOTAL				$2,275.00
TOTAL CONSTRUCTION ESTIMATE				$7,010.00

Unit prices for each of items are taken from the 4th quarter 2014 bid bridges provided by KDOT. A similar process was used for finding the installation costs for other fill heights (7 ft., 13 ft., and 20 ft.) The installation costs for all the fill heights are given in the following table.

Table 11. Installation Costs for Flattening the Foreslope to 1:3 for Different Fill Heights

1:3	Cost
H1	$7,010
H7	$55,830
H13	$176,456
H20	$406,680

Flattening the Foreslope to 1:6

For flattening the foreslope to 1:6 clear-zone distance was taken into consideration. The width of clear-zone distances was selected from the following table in roadside design guide.

TABLE 3.1 (Cont'd)

[U.S. Customary Units]

DESIGN SPEED	DESIGN ADT	FORESLOPES			BACKSLOPES		
		1V:6H of flatter	1V:5H TO 1V:4H	1V:3H	1V:3H	1V:5H TO 1V:4H	1V:6H or Flatter
40 mph or less	UNDER 750	7 – 10	7 – 10	**	7 – 10	7 – 10	7 – 10
	750 – 1500	10 – 12	12 – 14	**	10 – 12	10 – 12	10 – 12
	1500 – 6000	12 – 14	14 – 16	**	12 – 14	12 – 14	12 – 14
	OVER 6000	14 – 16	16 – 18	**	14 – 16	14 – 16	14 – 16
45–50 mph	UNDER 750	10 – 12	12 – 14	**	8 – 10	8 – 10	10 – 12
	750 – 1500	12 – 14	16 – 20	**	10 – 12	12 – 14	14 – 16
	1500 – 6000	16 – 18	20 – 26	**	12 – 14	14 – 16	16 – 18
	OVER 6000	18 – 20	24 – 28	**	14 – 16	18 – 20	20 – 22
55 mph	UNDER 750	12 – 14	14 – 18	**	8 – 10	10 – 12	10 – 12
	750 – 1500	16 – 18	20 – 24	**	10 – 12	14 – 16	16 – 18
	1500 – 6000	20 – 22	24 – 30	**	14 – 16	16 – 18	20 – 22
	OVER 6000	22 – 24	26 – 32 *	**	16 – 18	20 – 22	22 – 24
60 mph	UNDER 750	16 – 18	20 – 24	**	10 – 12	12 – 14	14 – 16
	750 – 1500	20 – 24	26 – 32 *	**	12 – 14	16 – 18	20 – 22
	1500 – 6000	26 – 30	32 – 40 *	**	14 – 18	18 – 22	24 – 26
	OVER 6000	30 – 32 *	36 – 44 *	**	20 – 22	24 – 26	26 – 28
65–70 mph	UNDER 750	18 – 20	20 – 26	**	10 – 12	14 – 16	14 – 16
	750 – 1500	24 – 26	28 – 36 *	**	12 – 16	18 – 20	20 – 22
	1500 – 6000	28 – 32 *	34 – 42 *	**	16 – 20	22 – 24	26 – 28
	OVER 6000	30 – 34 *	38 – 46 *	**	22 – 24	26 – 30	28 – 30

Figure 32. Suggested Clear-Zone Distance Table, Roadside Design Guide

For 1:6 foreslopes, the clear-zone distance varies for each AADT and design speed. As the clear-zone distance varies, the installation cost varies for each AADT, design speed, and shoulder width. The procedure for calculating the installation costs for an AADT of 750 vpd, a design speed of 45 mph, a shoulder width of 2 ft. and a fill height of 1 ft. is as follows

Table 12. Segment Characteristics

Segment Length (ft.)	2000
Fill Height (ft.)	1
Original Slope	1:1
Final Slope	1:6
Shoulder Width (ft.)	2
Clear-Zone Width (ft.)	10
Clear-Zone Foreslope Width (ft.)	8

Table 13. Area and Volume Calculations

Fill Area (sq. ft.)	2.50
Fill Volume (cu yd.)	185.20
Excavation Volume (cu yd.)	246.90
R/W Area (acre)	0.32
Seed Area (acre)	0.37

Fill area: The remaining portion of the 1:3 triangle with a base of 3 ft. and a height of 1 ft. when a 1:1 triangle with a base of 1 ft. and a height of 1 ft. is assumed to already be present, the area = ½’ x 6’ x 1’ – ½’ x 1’ x 1’ = 2.5 ft^2

Fill volume: 2.5 ft^2 area over 2,000 ft. length = 2.5 * 2,000/27 = 185.2 yd.

Excavation Volume = 185.2 / 0.75 = 246.9 yd^3

Seed area = 8/1 * 2000 / 43560 = 0.37 acres

Right of way area = (8-(1*1))*2000/43560 = 0.32 acres

Table 14. Final Price Details

ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
Clearing and Grubbing	1	Lump Sum	$1,000.00	$1,000.00
Common Excavation (Contractor Furnished)	246.9	cu. yd.	$6.23	$1538.00
Water (Grading) (Set)	1	Mgal	$35.00	$35.00
Compaction of Earth Work (Type AA) (MR 5-5)	185.2	Cu. Yd.	$1.90	$352.00
Field Office and Lab (Type C)	1	Each	$1,000.00	$1,000.00
Foundation Stabilization (Set)	1	Cu. Yd.	$50.00	$50.00
Contractor Construction Staking	1	Lump Sum	$800.00	$800.00
Mobilization (30 percent)	1			$1,433.00
ROAD TOTAL				$6208.00
MISCELLANEOUS				
Seeding	0.37	Acre	$1,000.00	$370.00
Right of Way	0.32	Acre	$1,500.00	$480.00
Traffic control	2	Lump sum	$1,000.00	$2,000.00
TOTAL				$2,850.00
TOTAL CONSTRUCTION ESTIMATE				$9058.00

Flattening the foreslope to 1:6 is calculated in similar way for various clear-zone widths. Clear-zone varies by AADT and Design speed as discussed.

Table 15. Installation Costs for Flattening the Foreslope to 1:6 for Different Clear-Zone Widths and Shoulder Widths

Shoulder Width-2 ft.

	Design Speed (mph) -AADT (vpd)	H1	H7	H13	H20
CL10	45-250,500	$9,058	$81,368	$225,611	$483,364
CL12	55-250,500	$9,283	$86,925	$237,089	$501,713
CL14	45-750,1000	$9,523	$92,226	$248,288	$519,778
CL16	45-1500; 55-750,1000; 60-250,500	$9,748	$97,120	$259,070	$537,462
CL18	55-1500; (65,70)-250,500	$9,973	$101,709	$269,563	$554,814
CL20	60-750,1000	$10,208	$106,027	$279,757	$571,910
CL24	60-1500; (65,70)-750,1000	$10,671	$113,542	$299,090	$604,980
CL26	(65,70)-1500	$11,028	$131,707	$308,285	$621,092

Shoulder Width-4 ft.

CL10	45-250,500	$8,833	$75,478	$213,846	$464,696
CL12	55-250,500	$9,058	$81,368	$225,611	$483,364
CL14	45-750,1000	$9,283	$86,925	$237,089	$501,713
CL16	45-1500; 55-750,1000; 60-250,500	$9,523	$92,226	$248,288	$519,778
CL18	55-1500; (65,70)-250,500	$9,748	$97,120	$259,070	$537,462
CL20	60-750,1000	$9,973	$101,709	$269,563	$554,814
CL24	60-1500; (65,70)-750,1000	$10,433	$109,914	$289,563	$588,589
CL26	(65,70)-1500	$10,671	$113,542	$299,090	$604,980

Shoulder Width-6ft.

CL10	45-250,500	$8,823	$69,216	$201,680	$445,672
CL12	55-250,500	$8,833	$75,478	$213,846	$464,696
CL14	45-750,1000	$9,058	$81,368	$225,611	$483,364
CL16	45-1500; 55-750,1000; 60-250,500	$9,283	$86,925	$237,089	$501,713
CL18	55-1500; (65,70)-250,500	$9,523	$92,226	$248,288	$519,778
CL20	60-750,1000	$9,748	$97,120	$259,070	$537,462
CL24	60-1500; (65,70)-750,1000	$10,208	$106,027	$279,757	$571,910
CL26	(65,70)-1500	$10,433	$109,914	$289,563	$588,589

Installing the Guardrail

Table 16. Segment Characteristics

Segment Length (ft.)	2000
Fill Height (ft.)	1
Original Slope	1:1
Final Slope	1:1

Table 17. Area and Volume Calculations

Fill Area (sq. ft.)	1.00
Fill Volume (cu yd.)	74.10
Excavation Volume (cu yd.)	98.80
Seed Area (acre)	0.05

Table 18. Guardrail Information

Flare Rate of Upstream Guardrail (X:1):	16
Length of Flared Guardrail (ft.)	37.50
Length of Guardrail Parallel with Highway (ft.)	1962.50
Total Length of Guardrail (ft.)	2000.00

Fill area: The remaining portion of the 1:3 triangle with a base of 3 ft. and a height of 1 ft. when a 1:1 triangle with a base of 1 ft. and a height of 1 ft. is assumed to already be present, the area =1' x 1' + ½' x 1' x 1' - ½' x 1' x 1' = 1 ft^2

Fill volume: 1 ft^2 area over 2,000 ft. length = 1* 2,000/27 = 74.1 yd.

Excavation Volume = 74.1 / 0.75 = 98.8 yd^3

Seed Area = (1 * 1)* 2000 / 43560 = 0.05 acres

Table 19. Final Price Details

ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
Clearing and Grubbing	1	Lump Sum	$1,000.00	$1,000.00
Common Excavation (Contractor Furnished)	98.8	cu. yd.	$6.23	$616.00
Water (Grading) (Set)	1	Mgal	$35.00	$35.00
Compaction of Earth Work (Type AA) (MR 5-5)	74.1	Cu. Yd.	$1.90	$141.00
Field Office and Lab (Type C)	1	Each	$1,000.00	$1,000.00
Foundation Stabilization (Set)	1	Cu. Yd.	$50.00	$50.00
Contractor Construction Staking	1	Lump Sum	$800.00	$800.00
Guardrail	2000	Ln Ft.	$33.72	$67,440.00
End Terminal	2	Each	$2,305.00	$4,610.00
Mobilization (30 percent)	1			$22,708.00
ROAD TOTAL				$98,400.00
MISCELLANEOUS				
Seeding	0.05	Acre	$1,000.00	$50.00
Traffic control	2	Lump sum	$1,000.00	$2,000.00
TOTAL				$2,050.00
TOTAL CONSTRUCTION ESTIMATE				**$100,450.00**

Guardrail installation costs for other fill heights were determined in the same way as above. The installation costs for other fill heights are given in Table 20.

Table 20. Installation Costs of Guardrail for Different Fill Heights

GL	Cost
H1	$100,450
H7	$108,215
H13	$116,795
H20	$126,858

APPENDIX C

An Example to Explain the Application of the Software in Both Versions of RSAP

To determine the cost-effectiveness countermeasures among the selected alternatives, the input data selected in one of the runs was listed below.

AADT: 500

Design Speed: 45

Fill Height: 1 ft.

Shoulder Width: 2 ft.

Lane Width: 10 ft.

Segment Length: 2000 ft. (Tangent Segment)

Life: 25 years; and

Discount rate: 4 Percent

Installation costs for the alternatives were:

Alternative 1: Do nothing (1:1 foreslope), $0;

Alternative 2: Improving to 1:3 foreslope, $7,010;

Alternative 3: Improving to 1:6 foreslope, $9,283; and

Alternative 4: Installing a guardrail, $100,450.

Procedure Involved in RSAPv2

General Information for this example is shown in Figure 33.

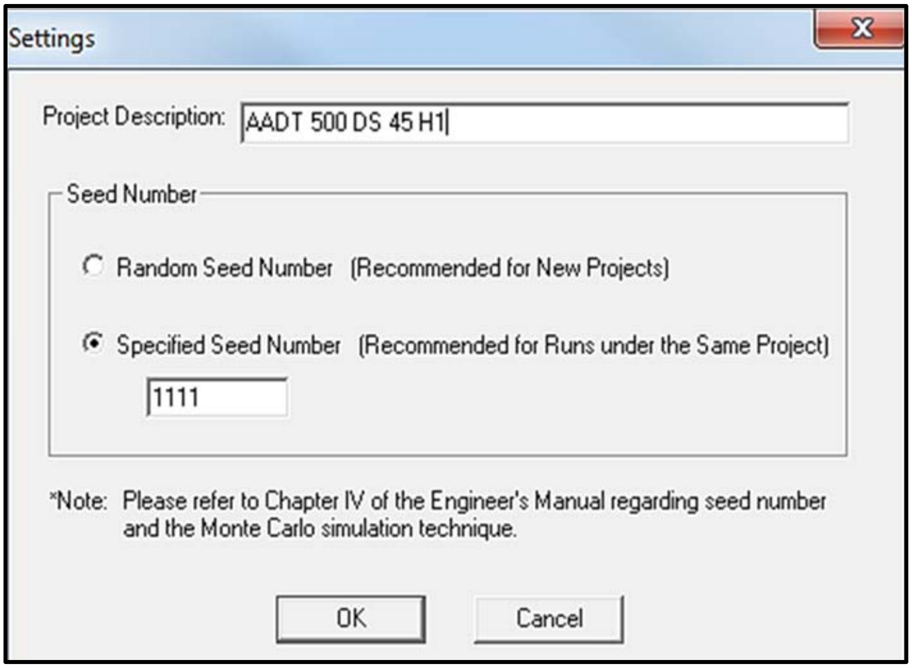


Figure 33. General Information

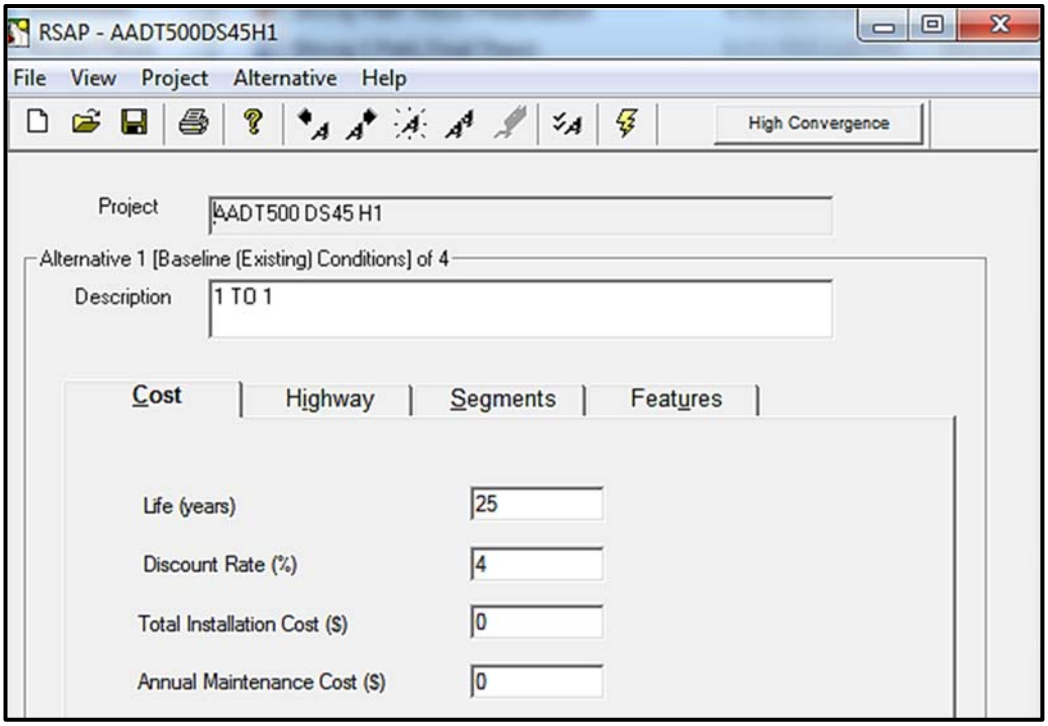


Figure 34. Alternative 1, Cost Information

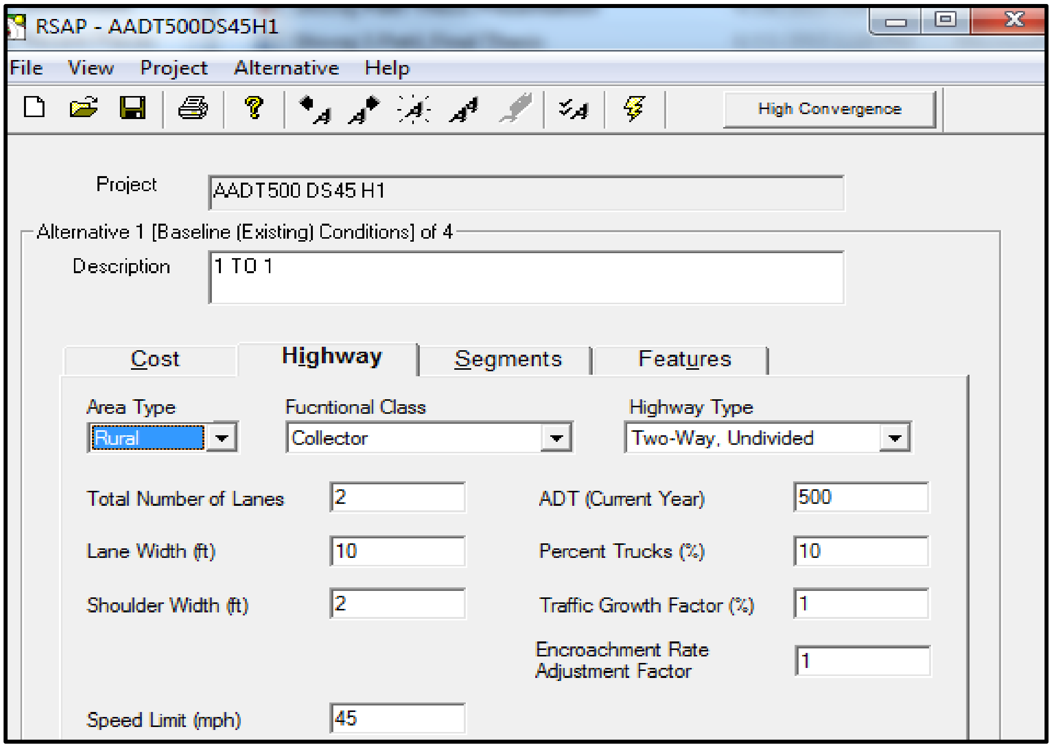


Figure 35. Alternative 1, Highway Characteristics

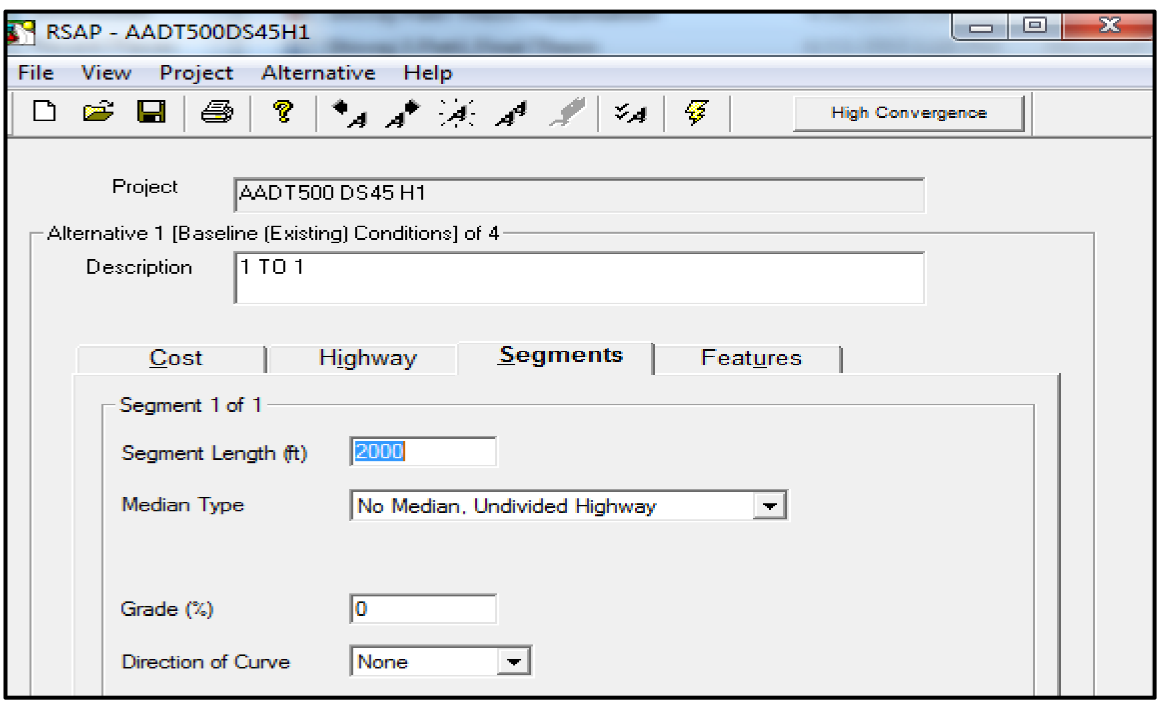


Figure 36. Alternative 1, Segment Characteristics

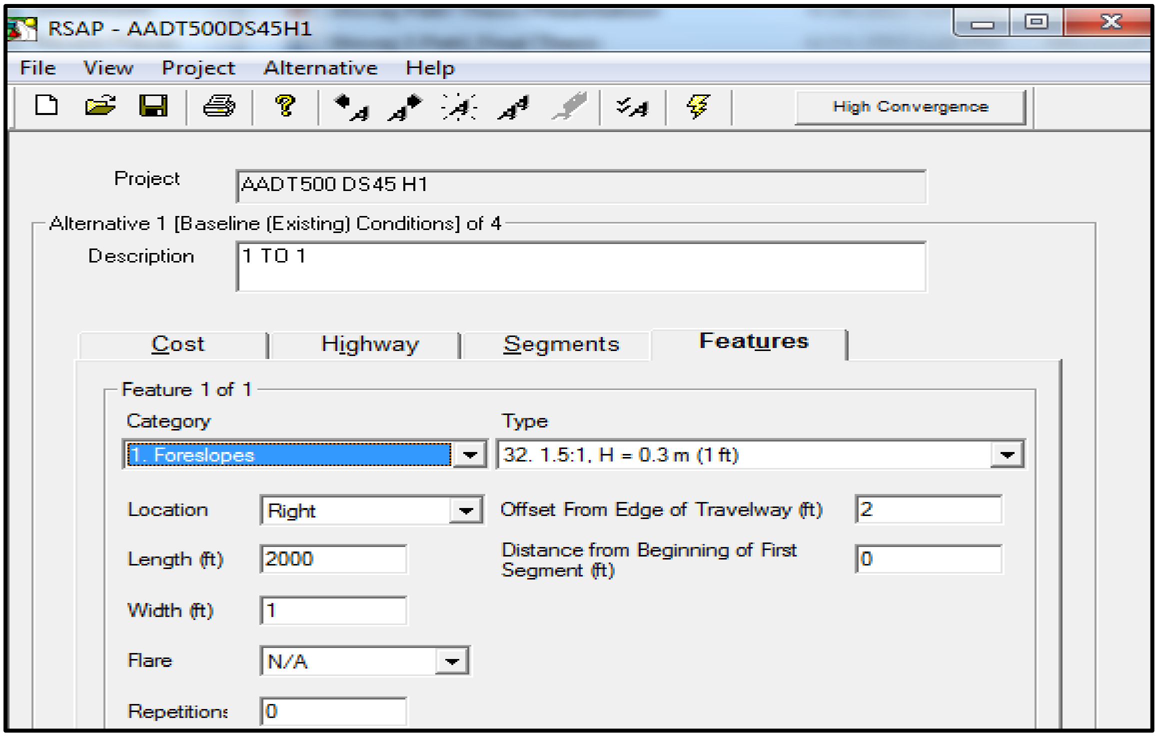


Figure 37. Alternative 1, Segment Features

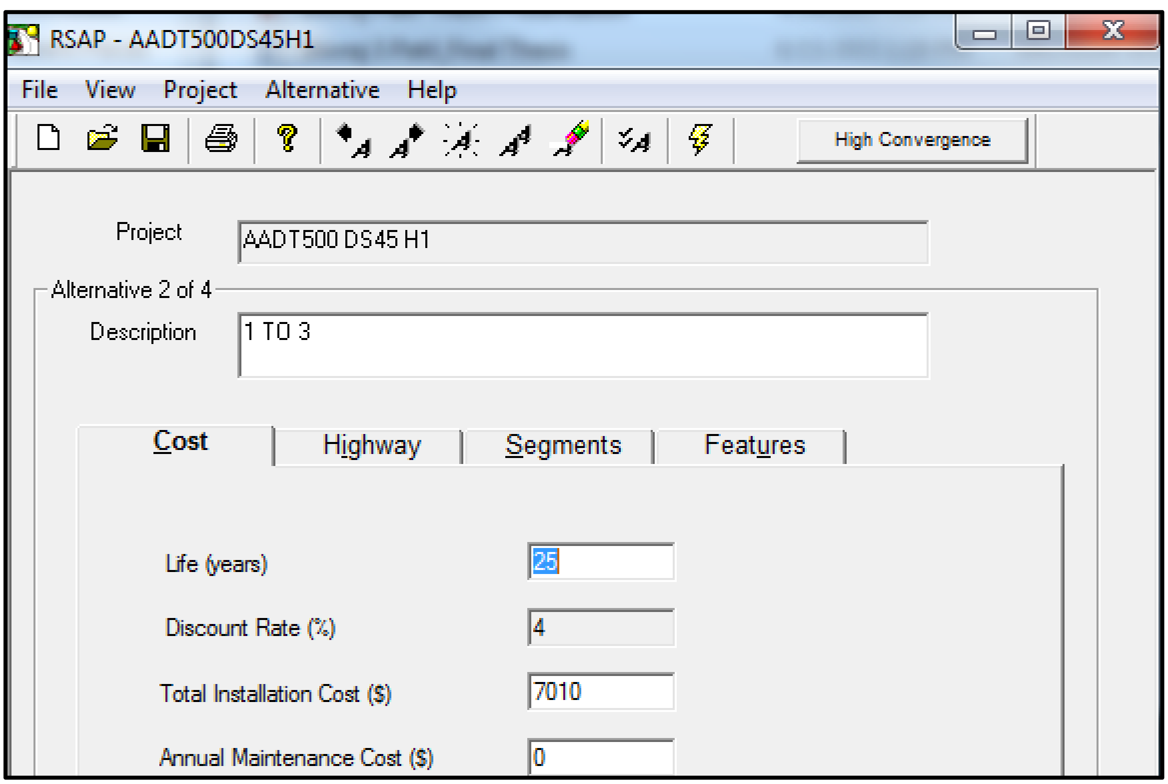


Figure 38. Alternative 2, Cost Information

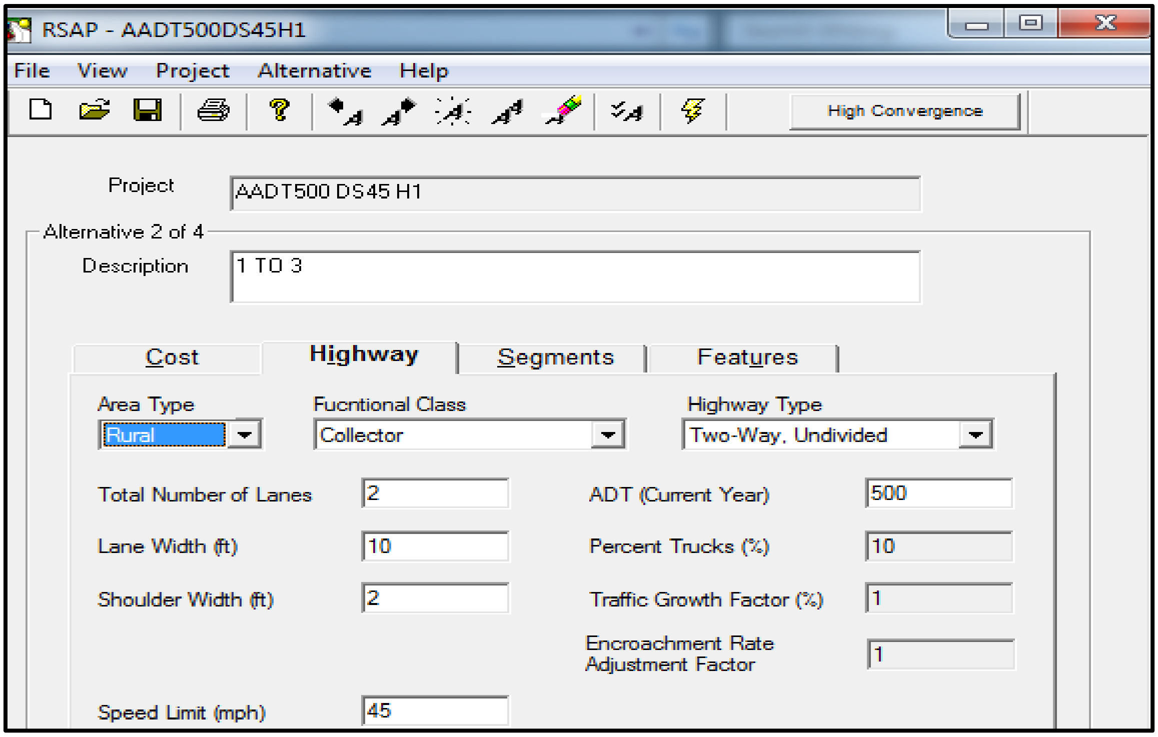


Figure 39. Alternative 2, Highway Characteristics

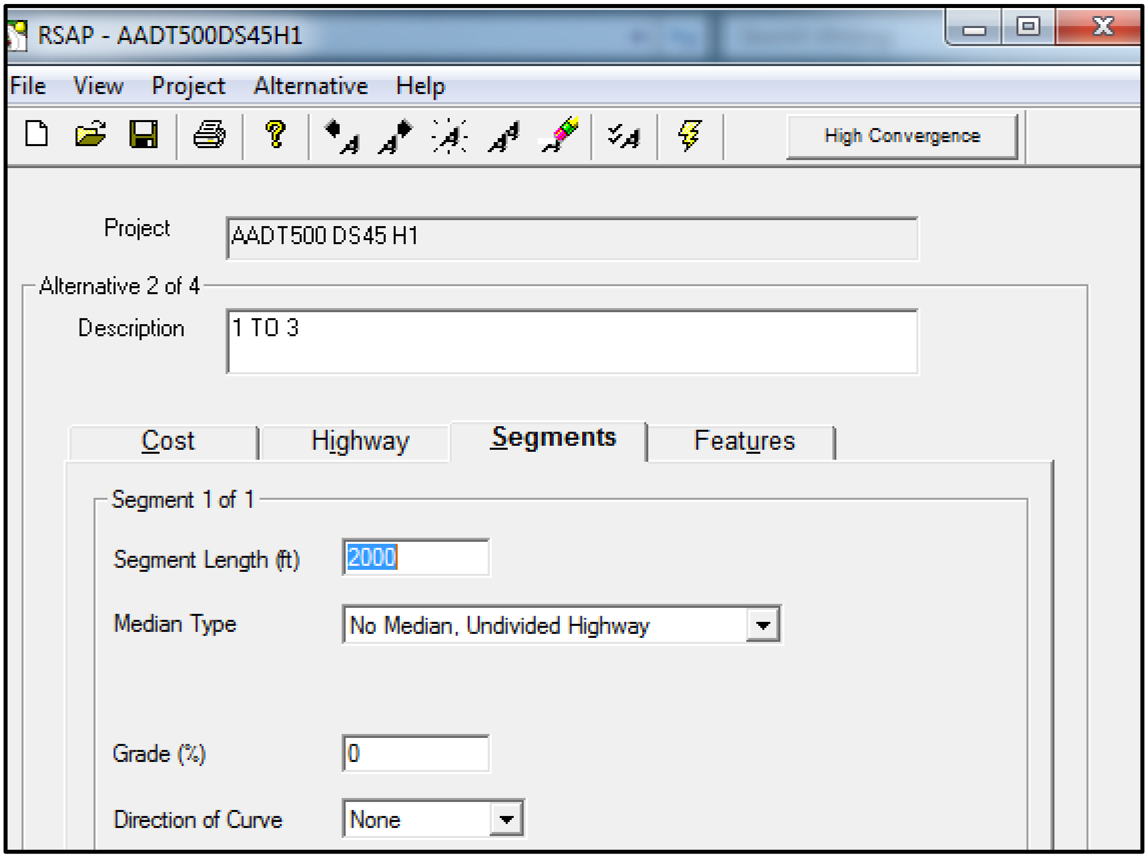


Figure 40. Alternative 2, Segment Characteristics

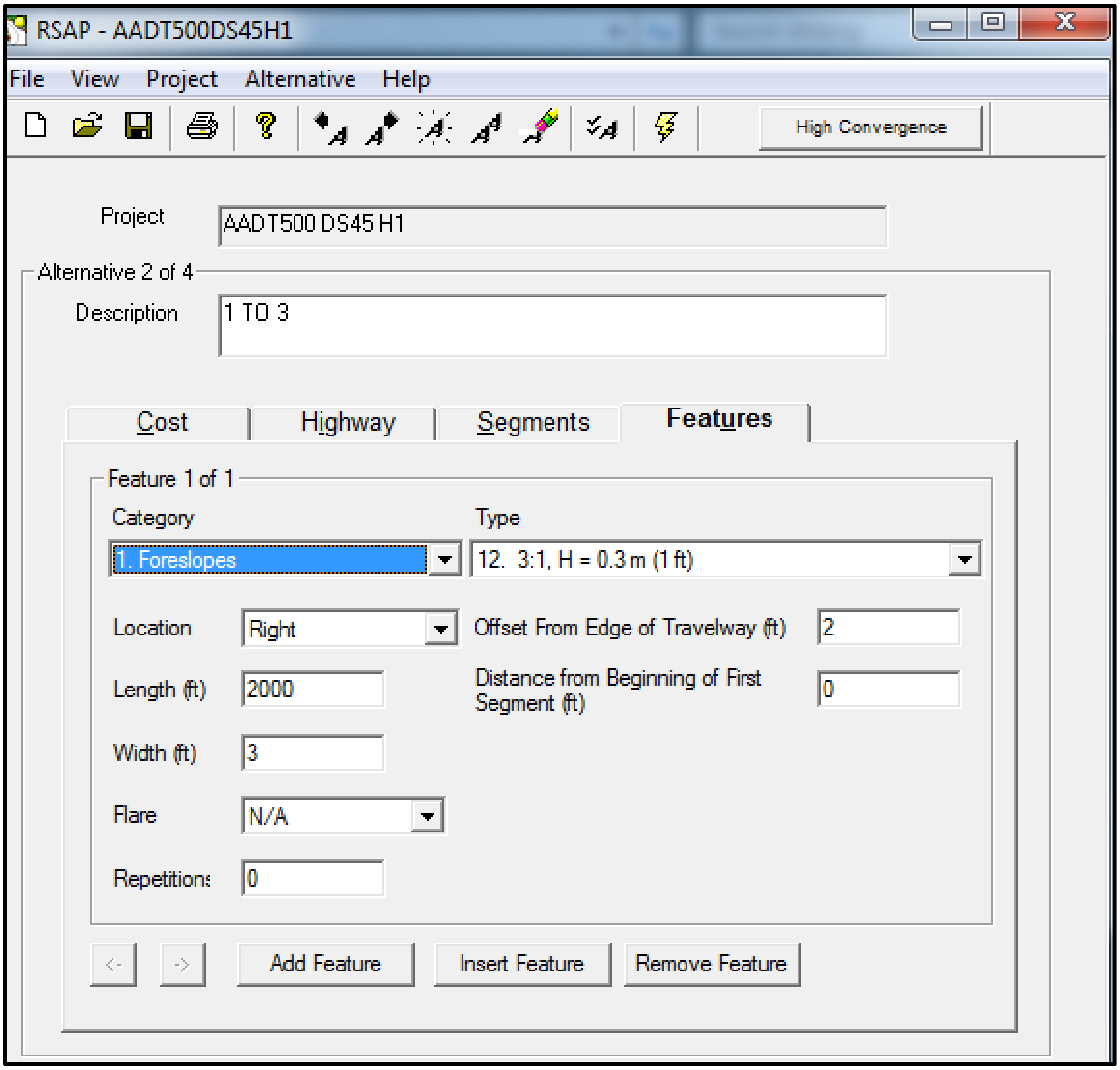


Figure 41. Alternative 2, Segment Features

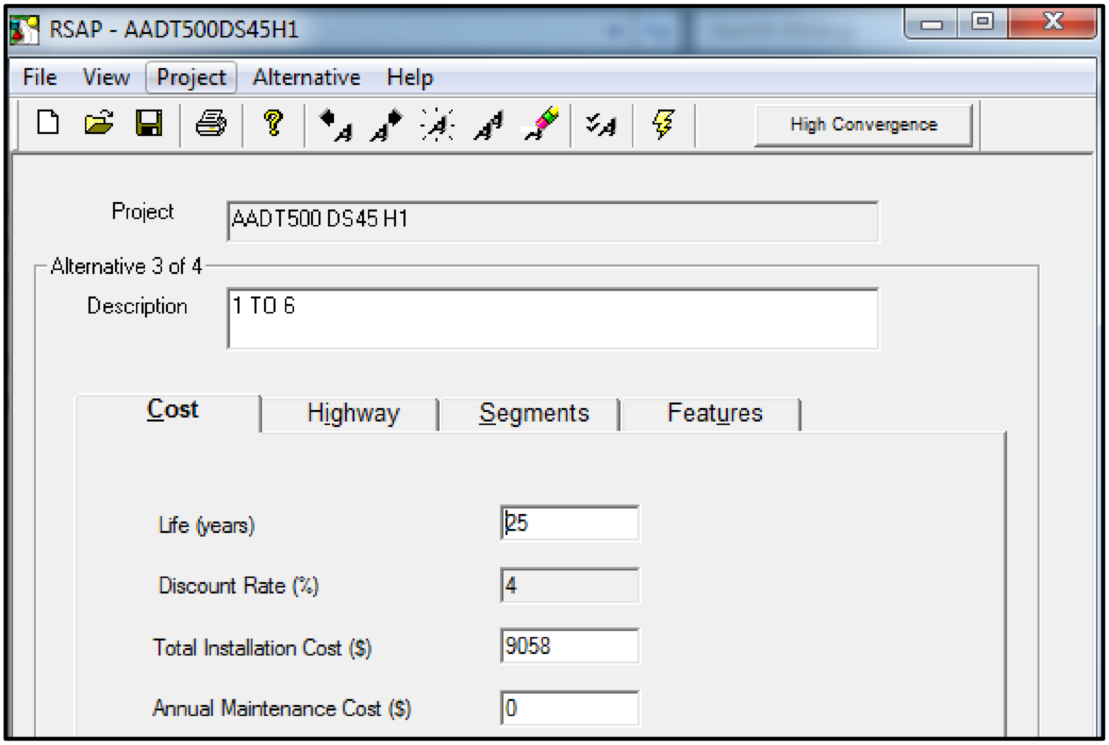


Figure 42. Alternative 3, Cost Information

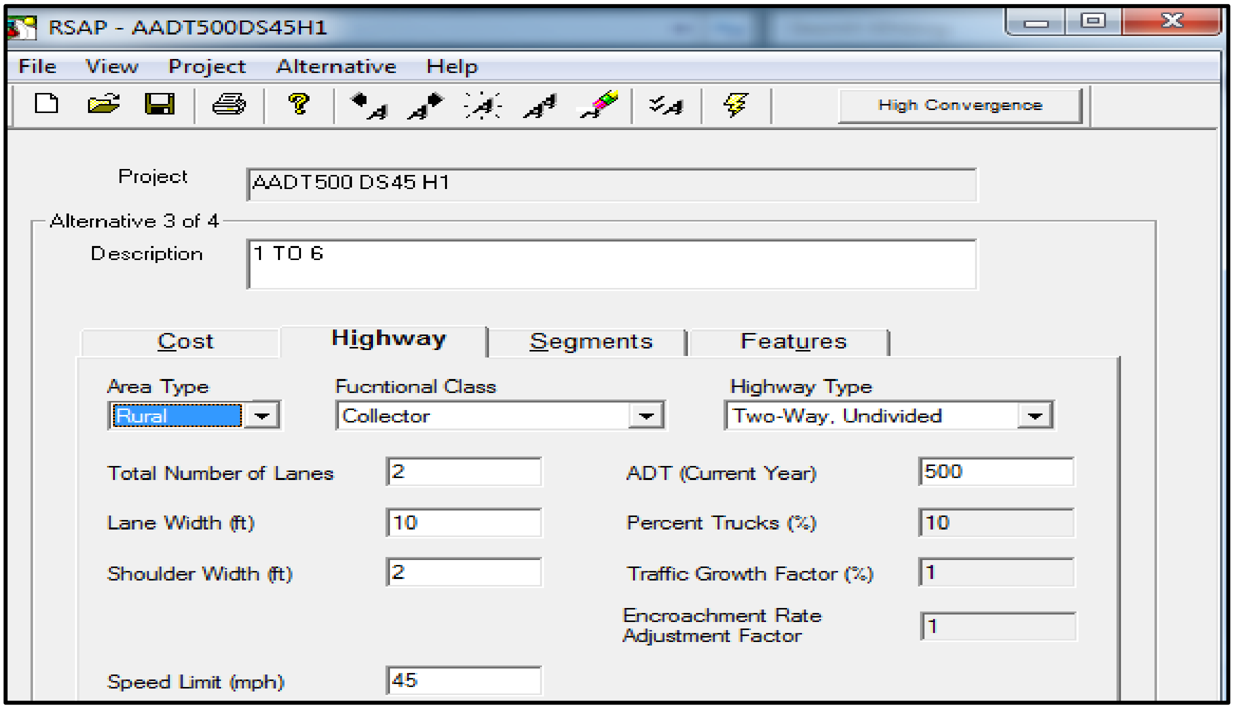


Figure 43. Alternative 3, Highway Characteristics

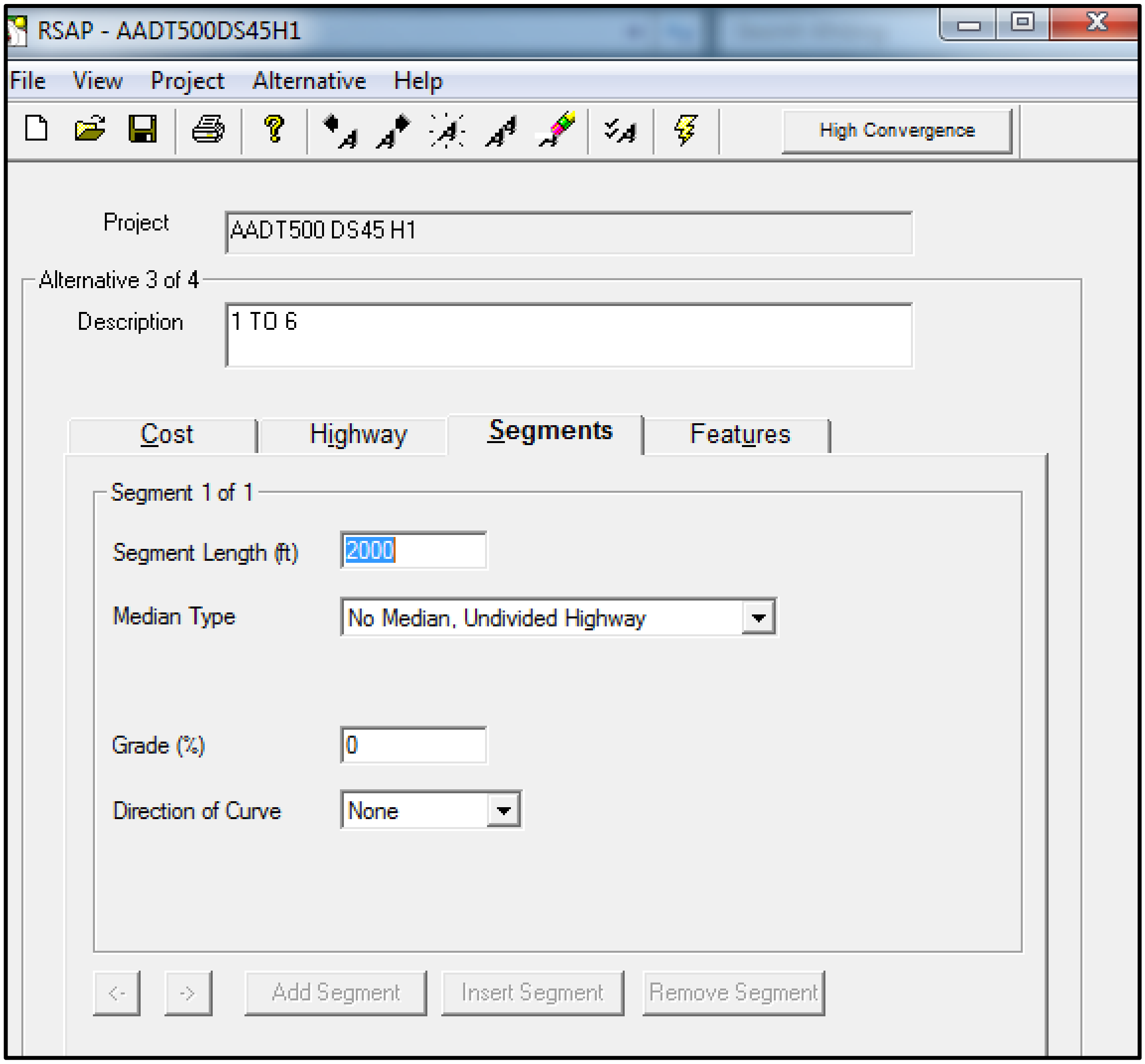


Figure 44. Alternative 3, Segment Characteristics

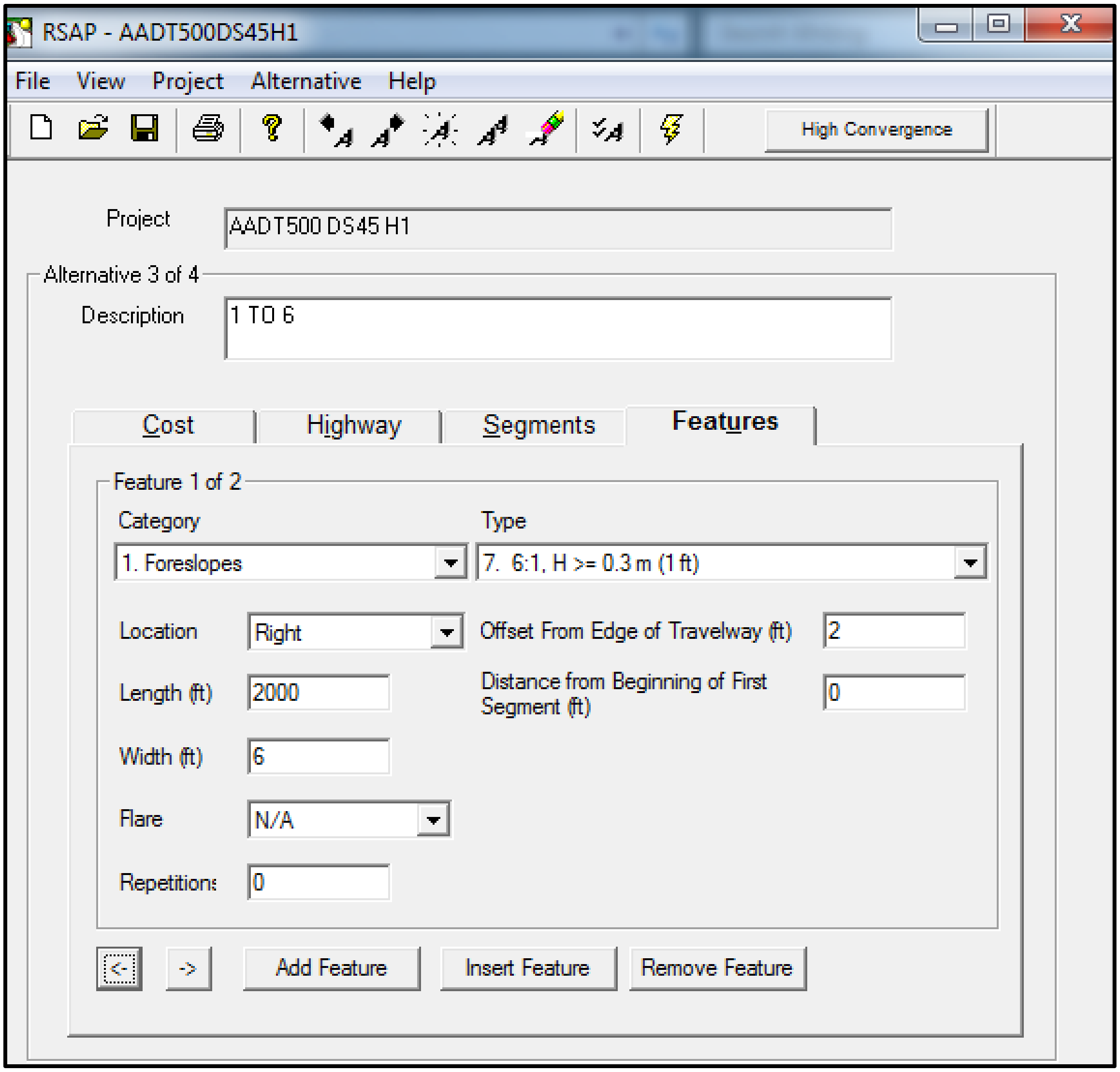


Figure 45. Alternative 3, Segment Feature 1 of 2

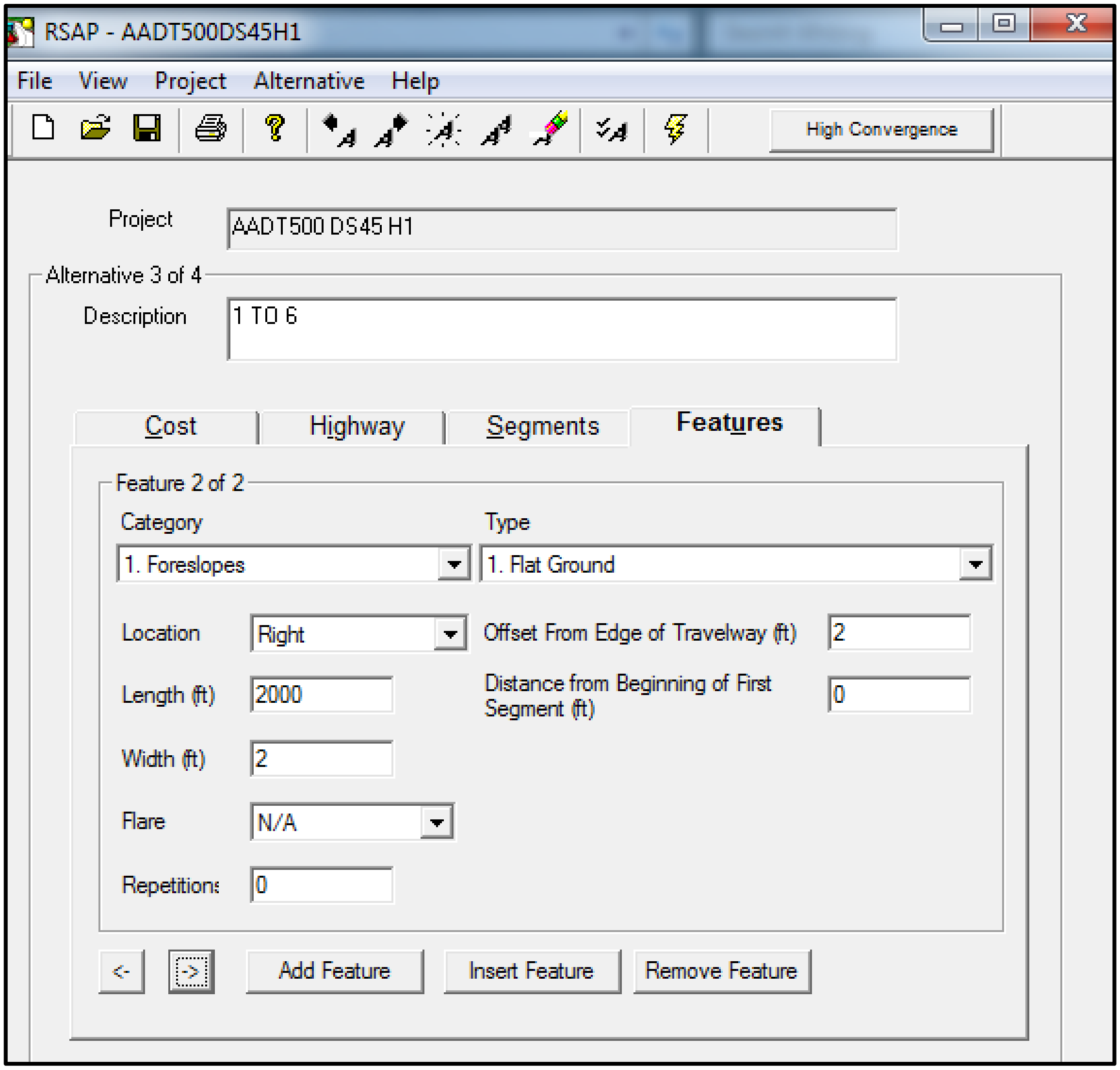


Figure 46. Alternative 3, Segment Feature 2 of 2

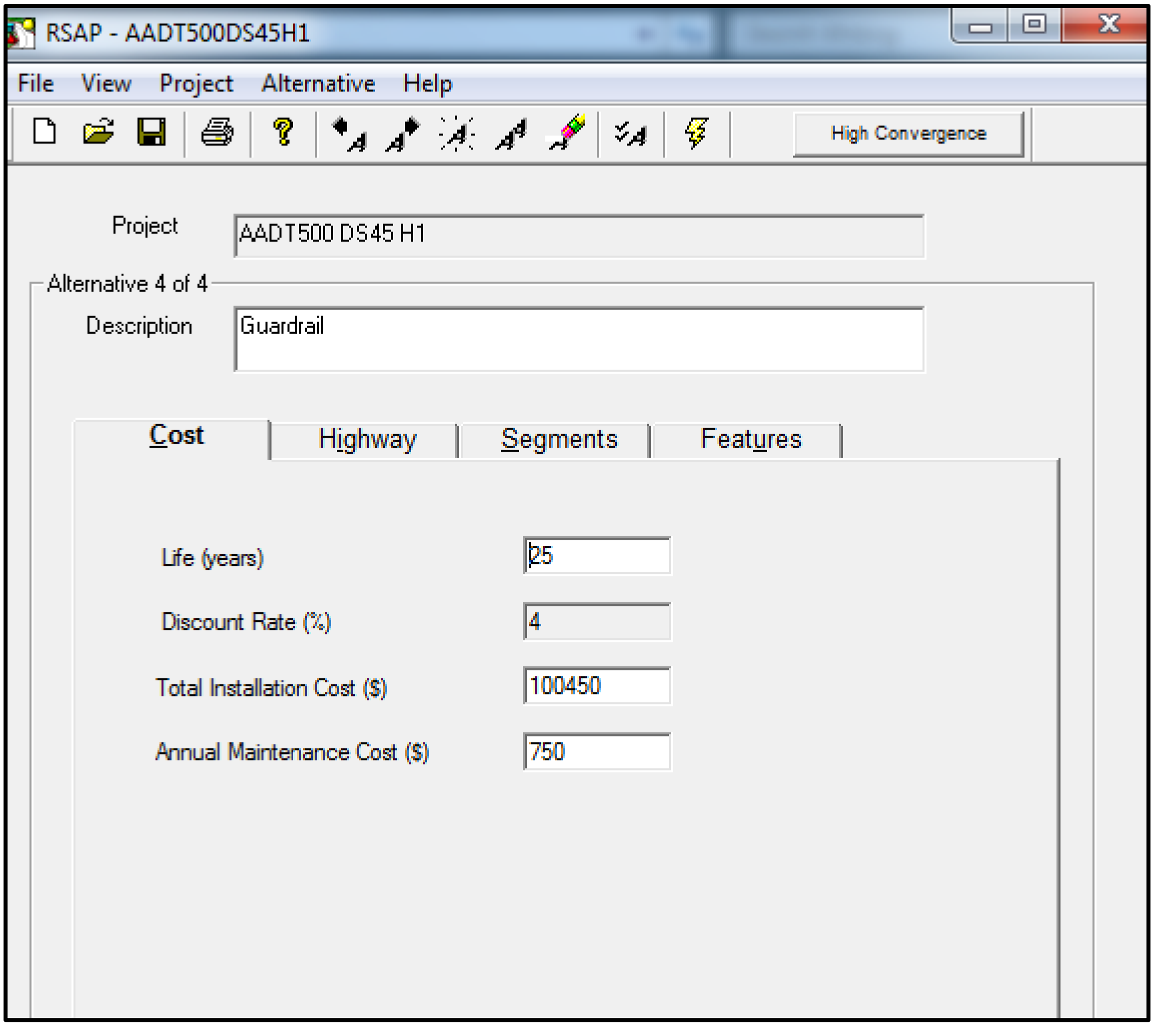


Figure 47. Alternative 4, Cost Information

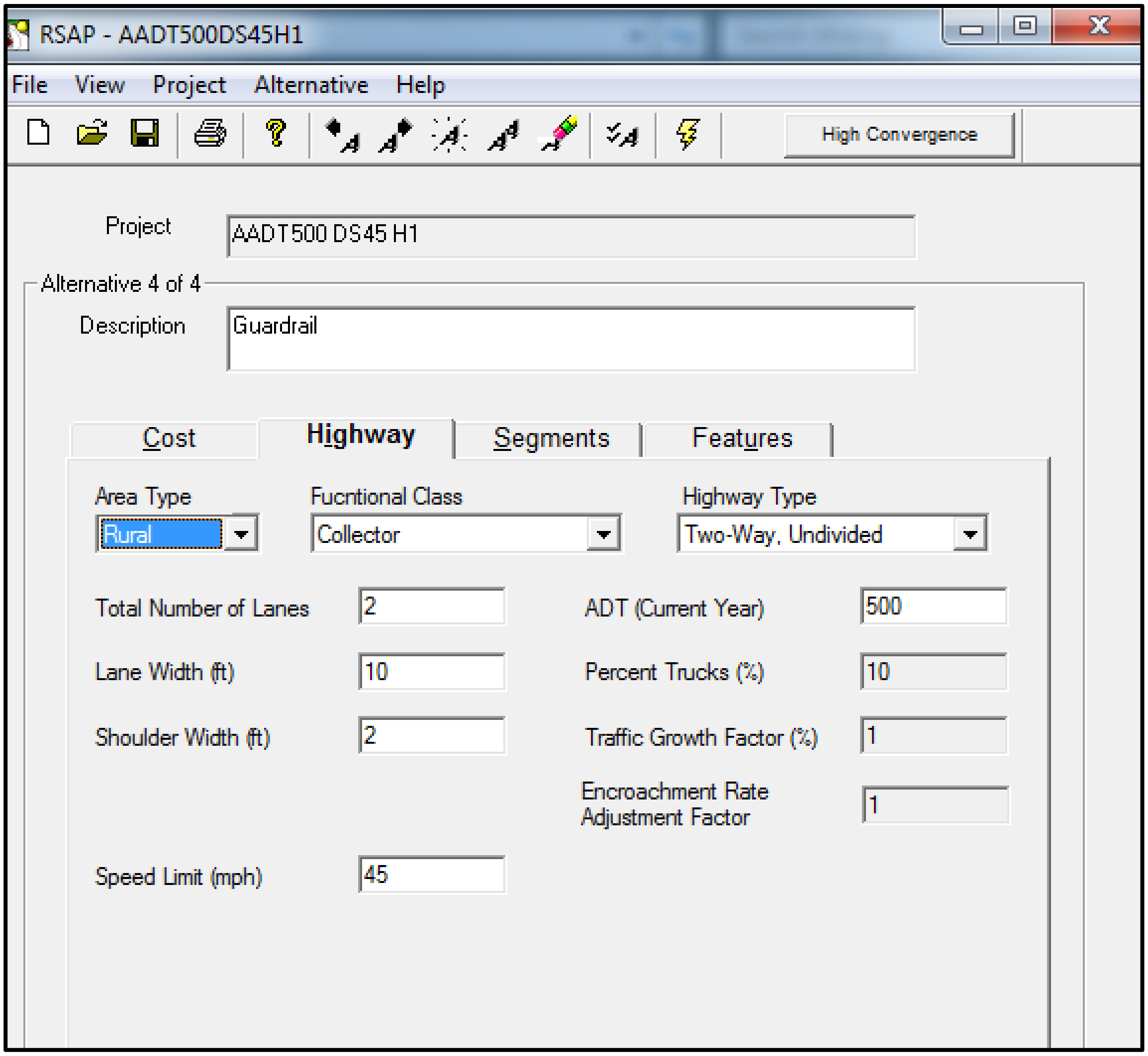


Figure 48. Alternative 4, Highway Characteristics

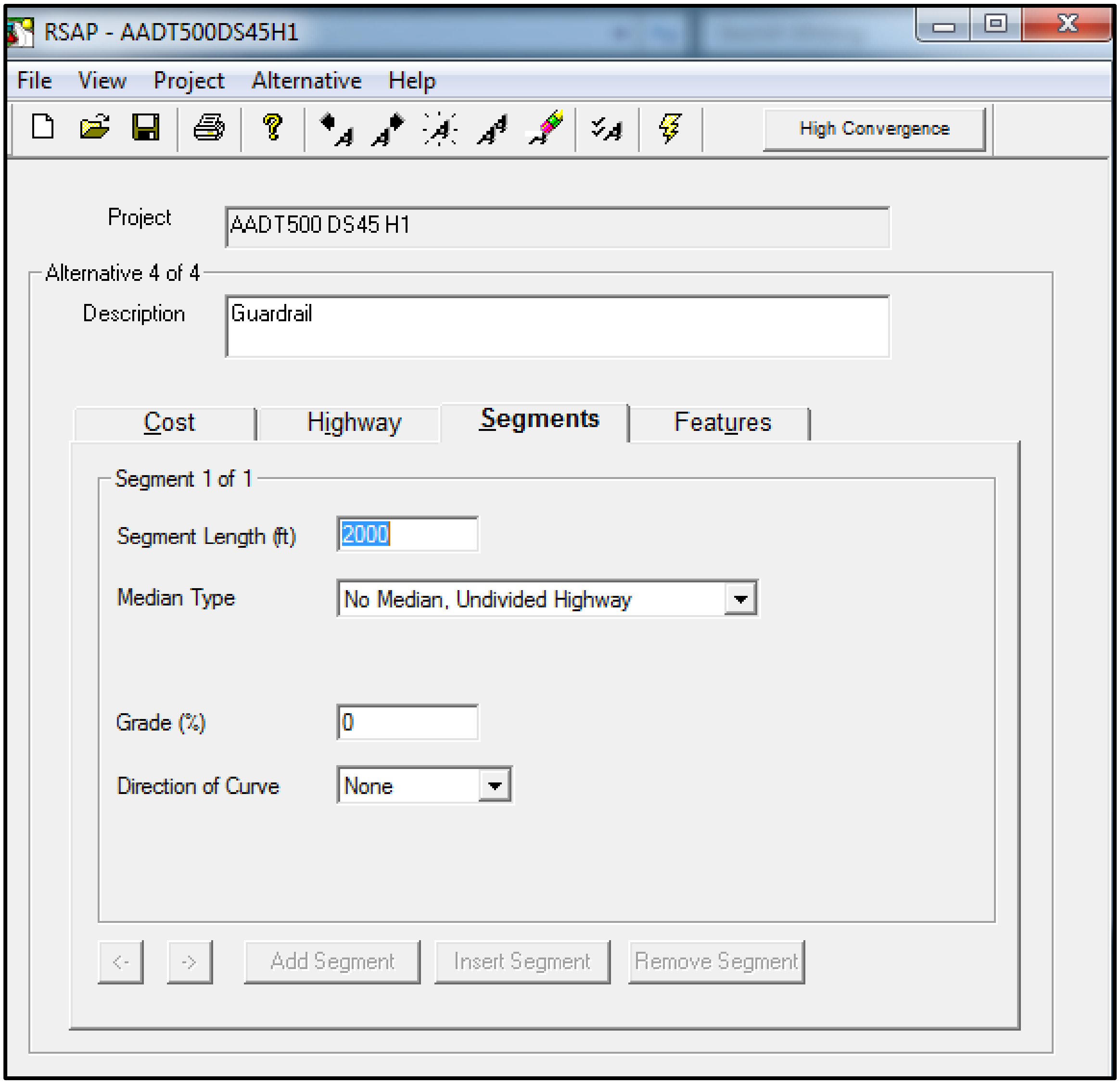


Figure 49. Alternative 4, Segment Characteristics

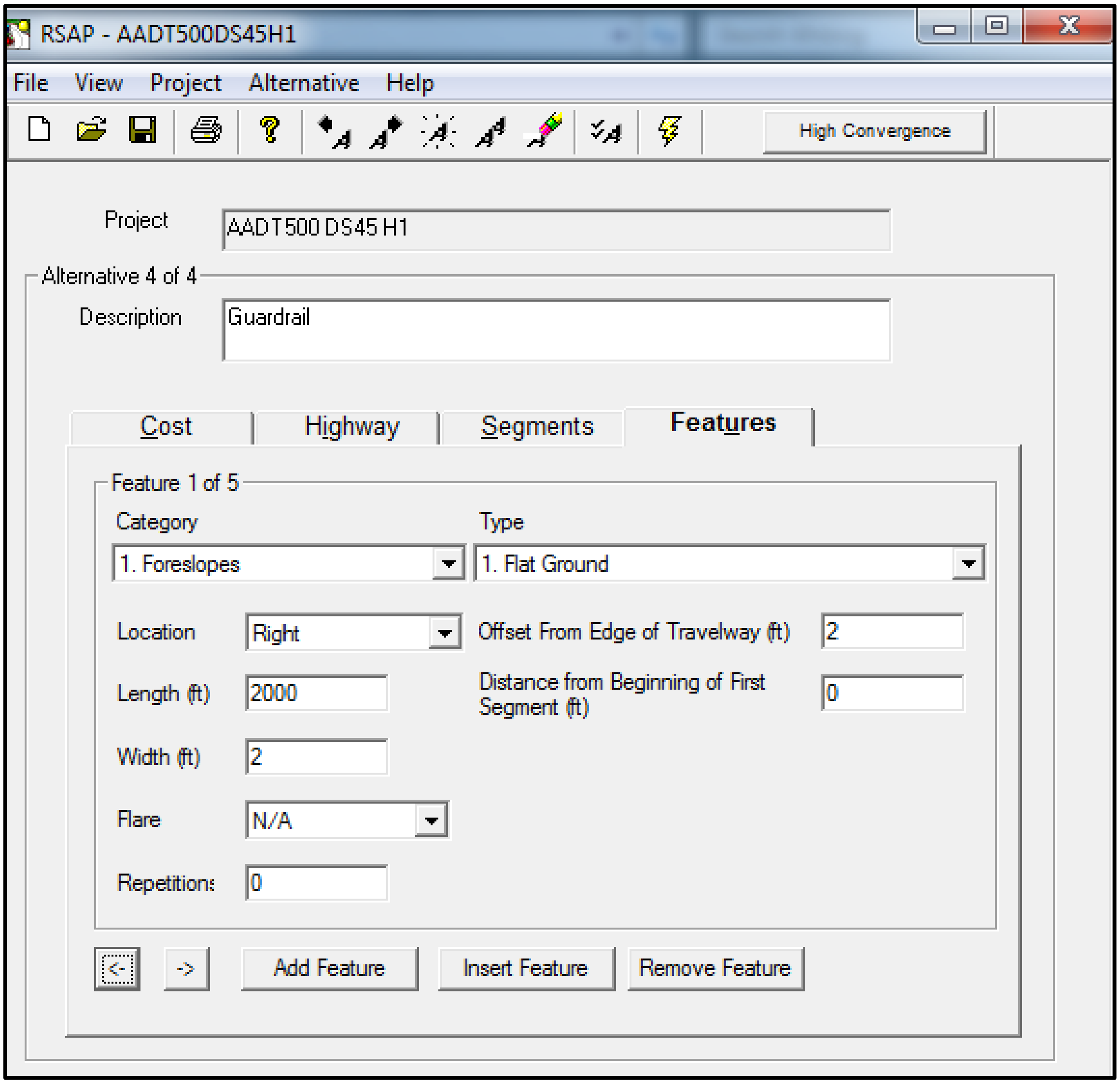


Figure 50. Alternative 4, Segment Feature 1 of 5

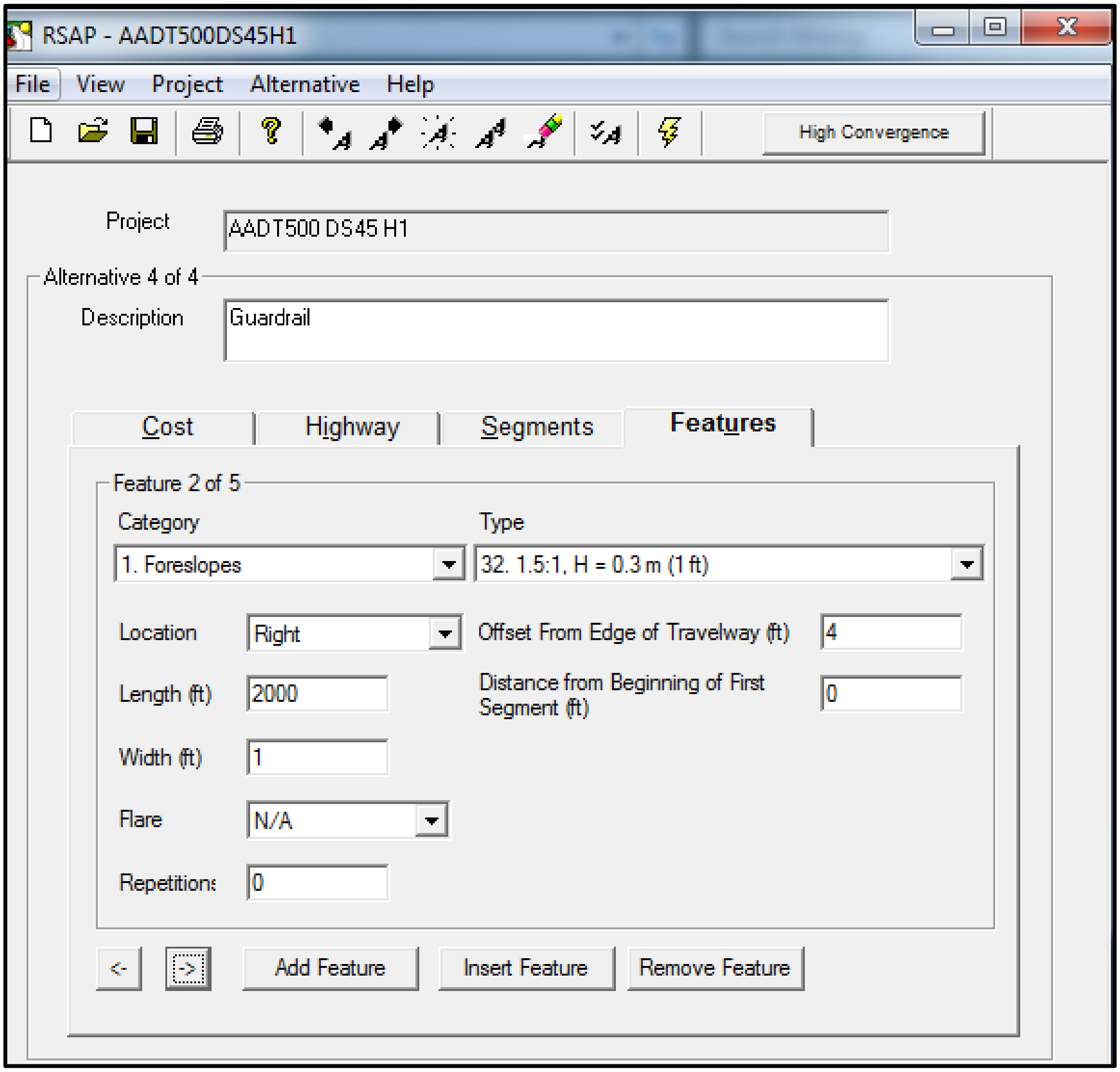


Figure 51. Alternative 4, Segment Feature 2 of 5

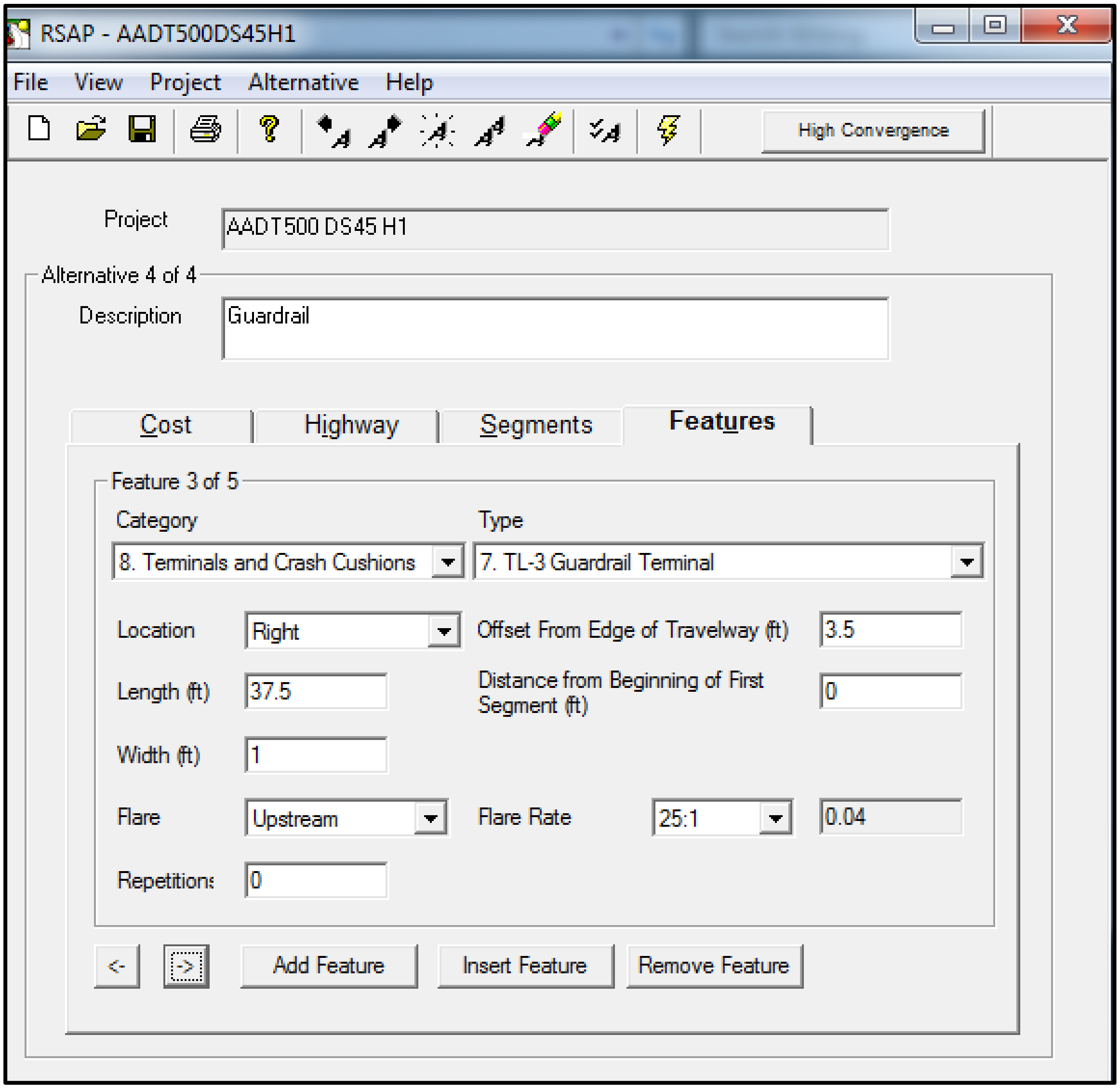


Figure 52. Alternative 4, Segment Feature 3 of 5

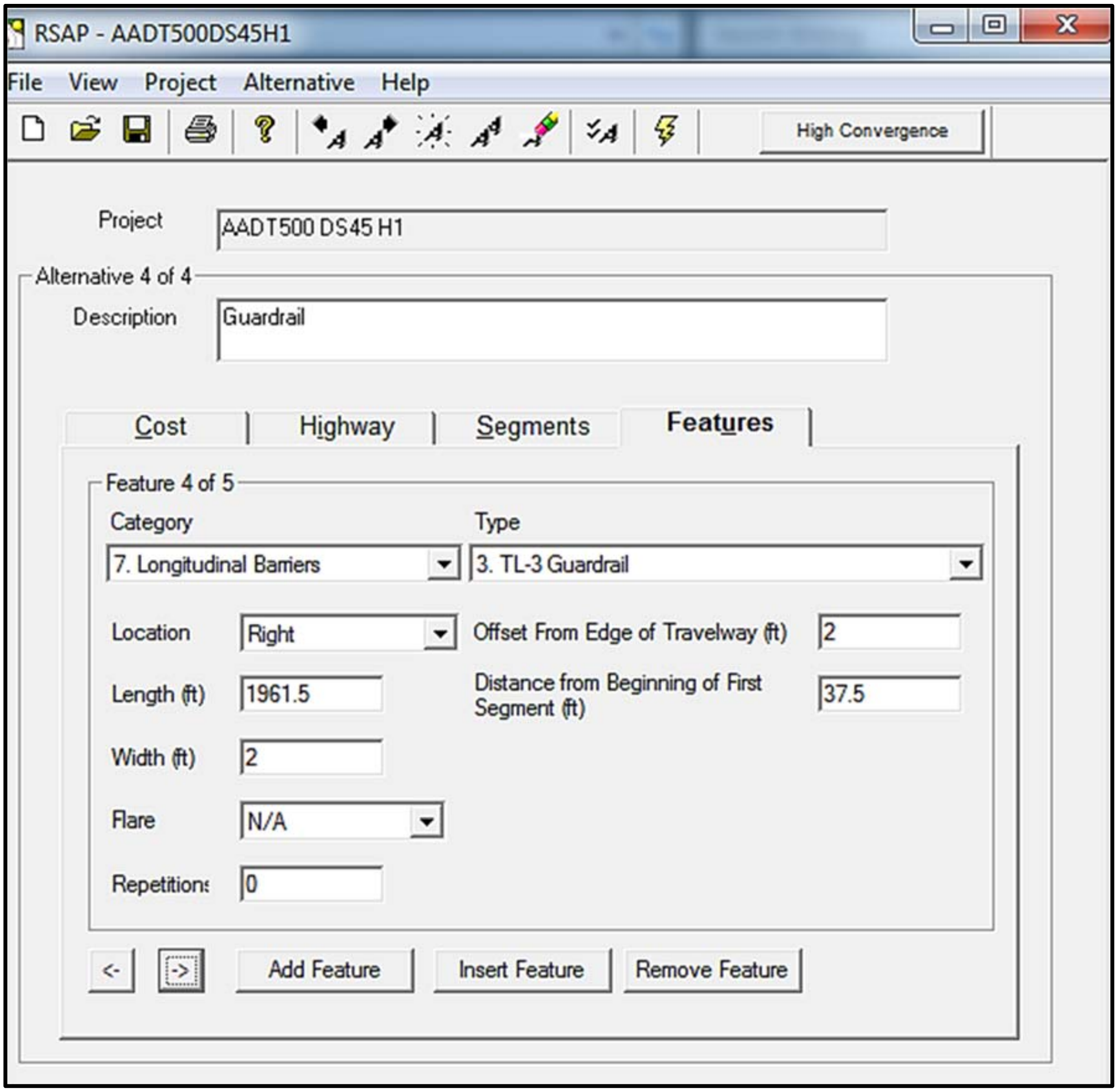


Figure 53. Alternative 4, Segment Feature 4 of 5

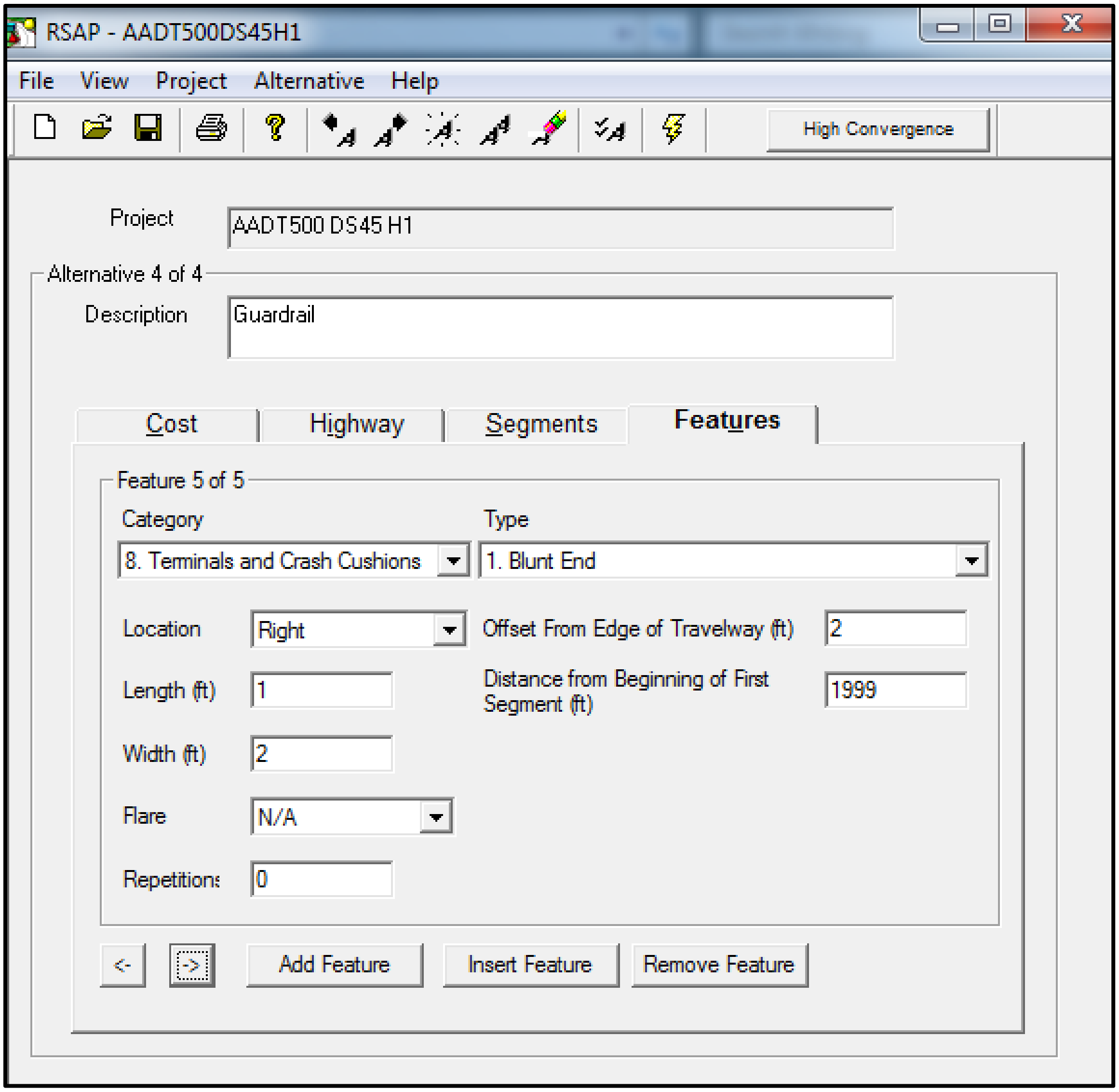


Figure 54. Alternative 4, Segment Feature 5 of 5

This is the end of inputting the data. Hitting the analyze button on top of the window, the program will run and gives the benefit-cost ratio for the four alternatives. The benefit-cost ratio table for this particular run is explained in Chapter 5.

Procedure Involved in RSAPv3

RSAP PROJECT INFORMATION

BASIC INFORMATION

Today's date (i.e., run date)	12/30/2016	
Title	AADT500DS45H1	
Units	USCU	(only USCU units at this time)
Design Life	25	YRS
Construction Year	2016	
Rate of Return	4	%

CRASH COSTS

Use GDP values during life?	N				
Expand to current year by GDP?	Y	http://www.gpoaccess.gov/usbudget/fy09/hist.html			
GDP Deflator to construction year	2	Crash Cost Timeline			
Base year for crash cost data	2009	2016	2028.5	2041	Cost Used
Value of Statistical Life	$ 6,000,000	$ 6,892,114	$ 6,892,114	$ 6,892,114	$6,892,114
Reference for VSL	Szabat and Knapp, "Treatment of the Economic Value of a Statistical Life in Departmental Analyses -- 2009 Annual Revision," U.S. DOT, March 18,2009.				

see http://regs.dot.gov

RSAP Root Directory: C:\Program Files\RSAPv3

Figure 55. General Information Tab

AADT500DS45H1

TRAFFIC INFORMATION

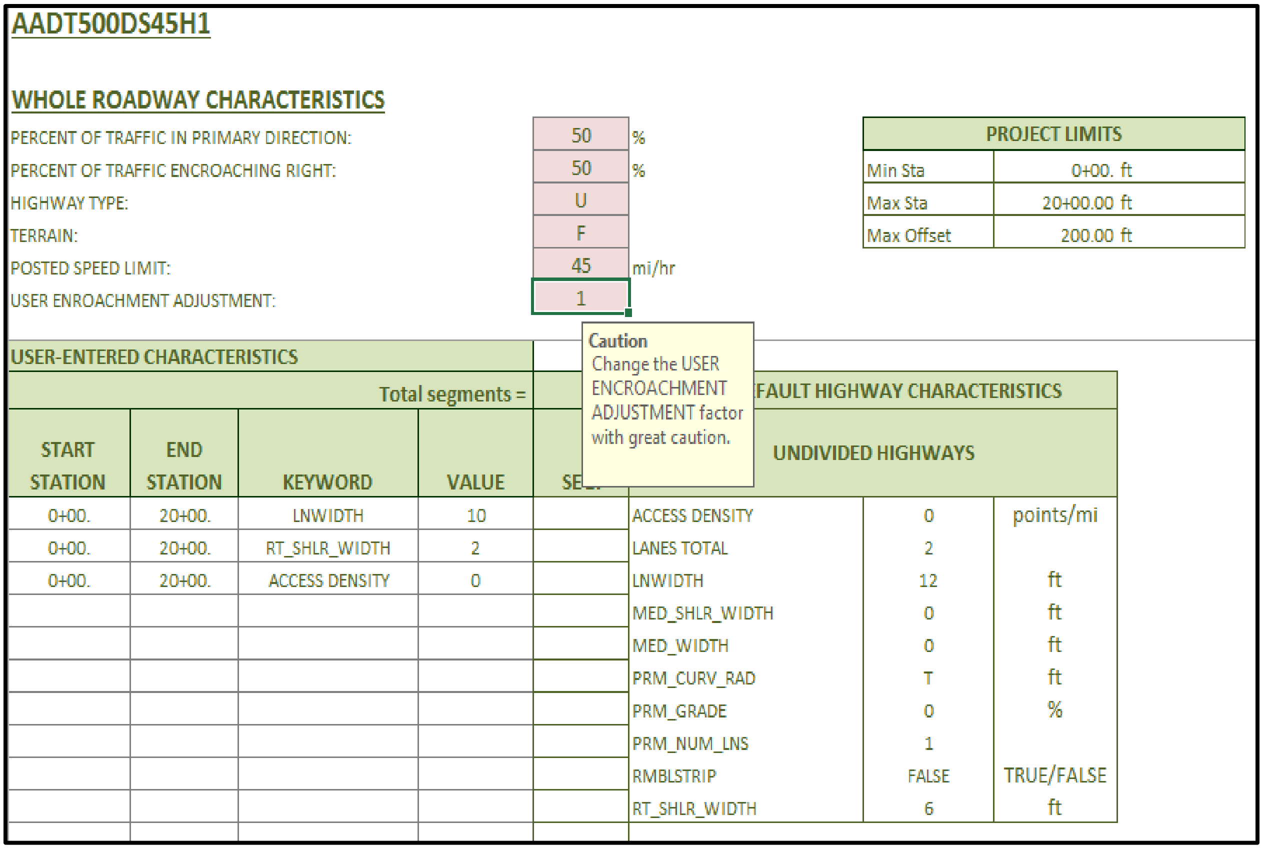
CONSTRUCTION YEAR ADT:	500	vehicles/day
TRAFFIC GROWTH	1.0	% growth/yr
WHICH ADT TO USE?	Mid-Life	
MID-LIFE ADT:	566	vehicles/day
END OF LIFE ADT:	641	vehicles/day
ADT USED BY RSAP	566	vehicles/day

VEHICLE MIX

RSAP VEHICLES	FHWA CLASS	PERCENT	RSAP TYPE	TYPICAL CHARACTERISTICS WEIGHT	LENGTH	WIDTH	C.G. Long.	C.G. Hgt	Crash Cost Adj.	Encr Multiplier	Mix Multiplier
		%		lbs	ft	ft	ft	ft			
Motorcycles	1	0.0	M	600	7.00	1.50	3.00	2.60	0.56	1.00	0.00
Passenger Vehicles	2	67.5	C	3,300	15.00	5.40	6.00	2.00	1.00	1.00	-0.75
PickupTruck	3	22.5	PU	5,000	19.75	6.50	8.50	2.30	1.00	1.00	-0.25
Light Tractor Trailer	8-9	0.0	LTT	16,000	48.00	8.50	12.00	4.8	3.52	0.30	0.00
Average Tractor Trailer	8-13	6.0	ATT	22,250	48.00	8.50	20.00	4.8	3.52	0.30	0.60
Heavy Tractor Trailer	8-13	0.0	HTT	37,500	48.00	8.50	20.00	6	3.52	0.30	0.00
Light Single Unit Truck	5	0.0	LSUT	6,800	35.00	7.77	12.50	3.4	3.52	0.30	0.00
Average Single Unit Truck	6	4.0	ASUT	12,000	35.00	7.77	12.50	3.4	3.52	0.30	0.40
Heavy Single Unit Truck	7	0.0	HSUT	22,000	35.00	7.77	12.50	4.2	3.52	0.30	0.00
Total		100.00									0.00

Click here for the on-line link to the FHWA classification system.

Figure 56. Traffic Information



AADT500DS45H1

WHOLE ROADWAY CHARACTERISTICS

PERCENT OF TRAFFIC IN PRIMARY DIRECTION:	50	%
PERCENT OF TRAFFIC ENCROACHING RIGHT:	50	%
HIGHWAY TYPE:	U	
TERRAIN:	F	
POSTED SPEED LIMIT:	45	mi/hr
USER ENROACHMENT ADJUSTMENT:	1	

PROJECT LIMITS	
Min Sta	0+00. ft
Max Sta	20+00.00 ft
Max Offset	200.00 ft

Caution
Change the USER ENCROACHMENT ADJUSTMENT factor with great caution.

USER-ENTERED CHARACTERISTICS

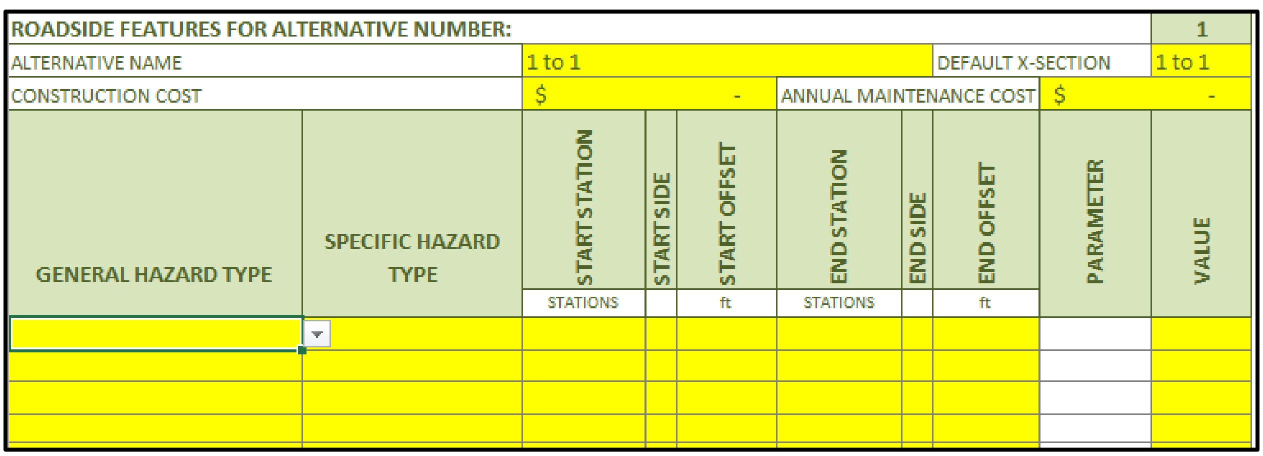
Total segments =

START STATION	END STATION	KEYWORD	VALUE	SE…
0+00.	20+00.	LNWIDTH	10	
0+00.	20+00.	RT_SHLR_WIDTH	2	
0+00.	20+00.	ACCESS DENSITY	0	

…FAULT HIGHWAY CHARACTERISTICS

UNDIVIDED HIGHWAYS		
ACCESS DENSITY	0	points/mi
LANES TOTAL	2	
LNWIDTH	12	ft
MED_SHLR_WIDTH	0	ft
MED_WIDTH	0	ft
PRM_CURV_RAD	T	ft
PRM_GRADE	0	%
PRM_NUM_LNS	1	
RMBLSTRIP	FALSE	TRUE/FALSE
RT_SHLR_WIDTH	6	ft

Figure 57. Highway Characteristics



ROADSIDE FEATURES FOR ALTERNATIVE NUMBER:										1
ALTERNATIVE NAME		1 to 1					DEFAULT X-SECTION			1 to 1
CONSTRUCTION COST		$ -			ANNUAL MAINTENANCE COST				$ -	
GENERAL HAZARD TYPE	SPECIFIC HAZARD TYPE	START STATION	START SIDE	START OFFSET	END STATION	END SIDE	END OFFSET		PARAMETER	VALUE
		STATIONS		ft	STATIONS		ft			

Figure 58. Alternative 1, Roadside Hazard Information

ROADSIDE FEATURES FOR ALTERNATIVE NUMBER:									2
ALTERNATIVE NAME		1:3				DEFAULT X-SECTION			3 to 1
CONSTRUCTION COST		$7,010			ANNUAL MAINTENANCE COST			$0	
GENERAL HAZARD TYPE	SPECIFIC HAZARD TYPE	START STATION	START SIDE	START OFFSET	END STATION	END SIDE	END OFFSET	PARAMETER	VALUE
		STATIONS		ft	STATIONS		ft		

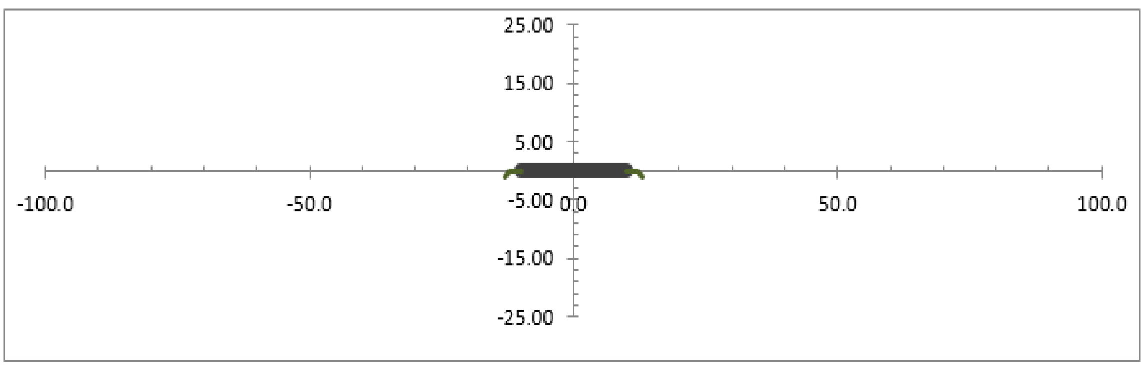
Figure 59. Alternative 2, Roadside Hazard Information

ROADSIDE FEATURES FOR ALTERNATIVE NUMBER:									3
ALTERNATIVE NAME		1:6				DEFAULT X-SECTION			6 to 1- FCL
CONSTRUCTION COST		$9,058			ANNUAL MAINTENANCE COST			$0	
GENERAL HAZARD TYPE	SPECIFIC HAZARD TYPE	START STATION	START SIDE	START OFFSET	END STATION	END SIDE	END OFFSET	PARAMETER	VALUE
		STATIONS		ft	STATIONS		ft		

Figure 60. Alternative 3, Roadside Hazard Information

ROADSIDE FEATURES FOR ALTERNATIVE NUMBER:									4
ALTERNATIVE NAME		Guard Rail					DEFAULT X-SECTION		Guard Rail
CONSTRUCTION COST		$100,450			ANNUAL MAINTENANCE COST			$750	
GENERAL HAZARD TYPE	SPECIFIC HAZARD TYPE	START STATION	START SIDE	START OFFSET	END STATION	END SIDE	END OFFSET	PARAMETER	VALUE
		STATIONS		ft	STATIONS		ft		
TerminalEnds	GenericEnd	0+00.	R	13.5	NA	NA	NA		24
MedianBarriers_SemiRigid	TL3WbeamMB	0+00.	R	13.5	0+37.50	R	12	Width (in.)	12
MedianBarriers_SemiRigid	TL3WbeamMB	0+37.50	R	12	20+00.00	R	12	Width (in.)	12
TerminalEnds	GenericEnd	20+00.00	R	12	NA	NA	NA		24

Figure 61. Alternative 4, Roadside Hazard Information

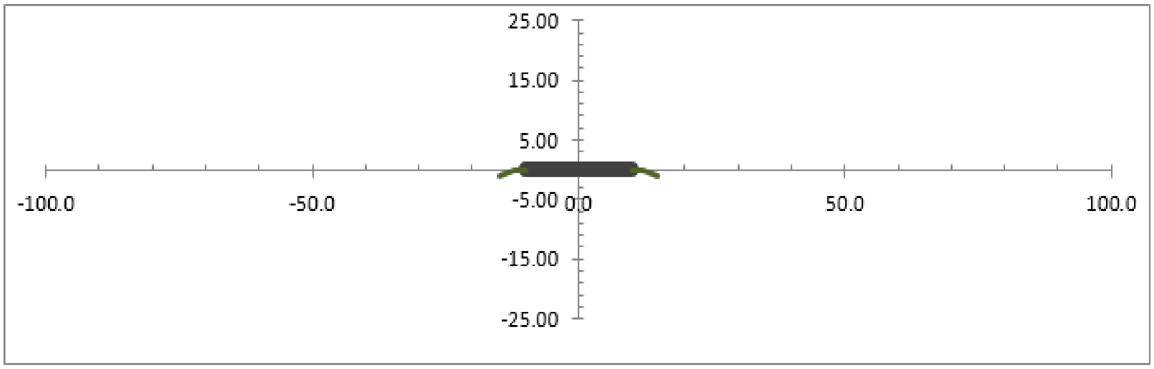


Name	1 to 1

	Primary Roadside Profile													
	Shoulder													
Slope Width	2.0	ft	1	ft	0	ft	0	ft	0	ft	0	ft	0	ft
Slope	0	H:1V	-1	H:1V		H:1V		H:1V		H:1V		H:1V	0	H:1V

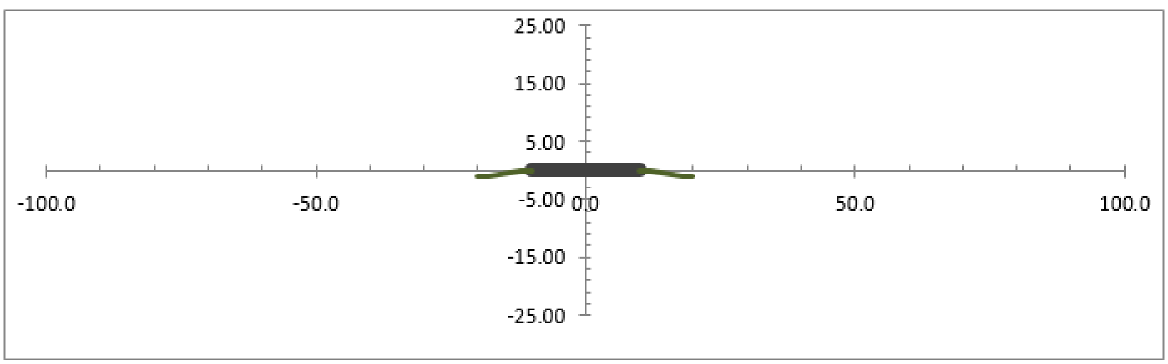
Offset	10.0	12.0	13.0	13.0	13.0	13.0	13.0	13.0
Elev	0.00	0.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

Figure 62. Original Cross-Section



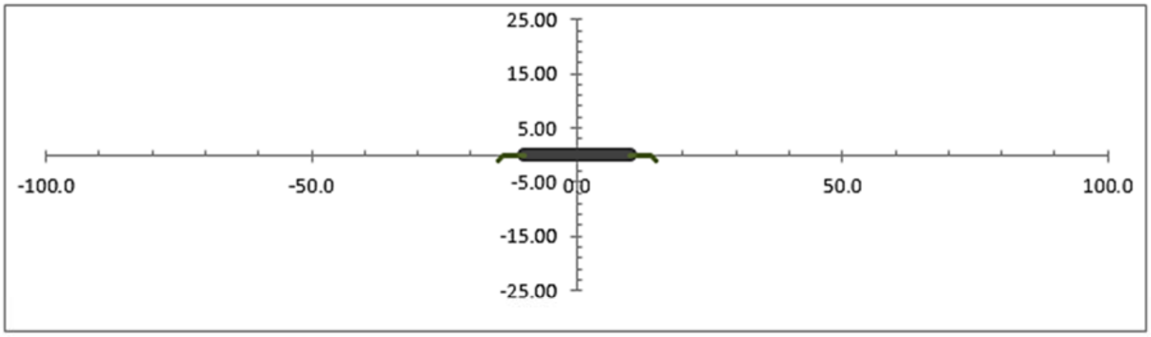
Name	1:3							
		Primary Roadside Profile						
		Shoulder	→					
Slope Width		2.0 ft	3 ft	0 ft	0 ft	0 ft	0 ft	0 ft
Slope		0 H:1V	-3 H:1V	H:1V	H:1V	H:1V	H:1V	0 H:1V
Offset	10.0	12.0	15.0	15.0	15.0	15.0	15.0	15.0
Elev	0.00	0.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

Figure 63. 1:3 Cross-Section



Name	1:6 - FCL 8							
		Primary Roadside Profile						
		Shoulder	→					
Slope Width		2.0 ft	6 ft	0 ft	0 ft	0 ft	0 ft	2 ft
Slope		0 H:1V	-6 H:1V	H:1V	H:1V	H:1V	0 H:1V	0 H:1V
Offset	10.0	12.0	18.0	18.0	18.0	18.0	18.0	20.0
Elev	0.00	0.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

Figure 64. 1:6 Cross-Section



Name	Guard Rail							
	Primary Roadside Profile							
	Shoulder							
Slope Width	2.0 ft	2 ft	1 ft	0 ft	0 ft	0 ft	0 ft	
Slope	0 H:1V	0 H:1V	-1 H:1V	H:1V	H:1V	H:1V	0 H:1V	
Offset	10.0	12.0	14.0	15.0	15.0	15.0	15.0	15.0
Elev	0.00	0.00	0.00	-1.00	-1.00	-1.00	-1.00	-1.00

Figure 65. Cross-Section for Guardrail

	DEFAULT X-SECTION		ALTERNATIVES				
			OC	(1:3)	1:6 - FCL 8	Guard Rail	
SEG	START STA	END STA	1	2	3	4	
1	0+00.	20+00.00	OC	(1:3)	1:6 - FCL 8	Guard Rail	

Figure 66. Cross-Sections Assigning to Each Alternative

This is the end of giving input in RSAPv3. Selecting the 'Run' option in the user interface window, will start the program to run and provides the benefit-cost ratio. The same procedure was followed to run the program for selected traffic and geometric characteristics in both the versions. Benefit-cost ratios for the above example and all the runs performed in both the versions is explained in Chapter 5. Interpretation of results and figures developed were also explained in Chapter 5.

APPENDIX D

Benefit-Cost Ratio Tables Used for the Analysis

Table 21. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-1 ft.; AADT-250&500 vpd

AADT 250 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	4.15	4.37	-0.05
1:3	0.00	0.00	5.14	-0.03
1:6	0.00	0.00	0.00	-0.44
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.23	8.60	0.03
1:3	0.00	0.00	9.73	-0.52
1:6	0.00	0.00	0.00	-0.75
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	10.81	11.00	0.11
1:3	0.00	0.00	11.46	-0.60
1:6	0.00	0.00	0.00	-0.92
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	14.41	14.29	0.27
1:3	0.00	0.00	14.01	-0.67
1:6	0.00	0.00	0.00	-1.10
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	17.95	17.94	0.43
1:3	0.00	0.00	17.94	-0.73
1:6	0.00	0.00	0.00	-1.27
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.20	8.64	-0.10
1:3	0.00	0.00	10.14	-0.65
1:6	0.00	0.00	0.00	-0.86
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	16.25	16.98	0.05
1:3	0.00	0.00	9.22	-1.03
1:6	0.00	0.00	0.00	-1.47
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	21.36	21.72	0.57
1:3	0.00	0.00	22.63	-0.82
1:6	0.00	0.00	0.00	-1.44
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	28.45	28.22	0.53
1:3	0.00	0.00	27.68	-1.33
1:6	0.00	0.00	0.00	-2.17
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	35.45	35.44	-0.86
1:3	0.00	0.00	35.44	-1.45
1:6	0.00	0.00	0.00	-2.51
Guardrail	0.00	0.00	0.00	0.00

Table 22. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-1 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	11.93	11.96	-0.14
1:3	0.00	0.00	12.03	-0.94
1:6	0.00	0.00	0.00	-1.26
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	23.66	23.54	0.08
1:3	0.00	0.00	23.23	-1.49
1:6	0.00	0.00	0.00	-2.15
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	31.09	30.19	0.82
1:3	0.00	0.00	28.21	-1.19
1:6	0.00	0.00	0.00	-2.11
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	41.42	38.39	0.77
1:3	0.00	0.00	32.61	-1.93
1:6	0.00	0.00	0.00	-3.18
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	51.60	48.22	1.25
1:3	0.00	0.00	41.75	-2.10
1:6	0.00	0.00	0.00	-3.68
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	15.53	15.56	-0.18
1:3	0.00	0.00	15.66	-1.23
1:6	0.00	0.00	0.00	-1.64
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	30.79	30.63	0.1
1:3	0.00	0.00	30.23	-1.94
1:6	0.00	0.00	0.00	-2.8
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	40.47	39.29	1.07
1:3	0.00	0.00	36.71	-1.55
1:6	0.00	0.00	0.00	-2.75
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	53.90	49.97	1.00
1:3	0.00	0.00	42.44	-2.52
1:6	0.00	0.00	0.00	-4.13
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	67.16	62.76	1.62
1:3	0.00	0.00	54.34	-2.74
1:6	0.00	0.00	0.00	-4.79
Guardrail	0.00	0.00	0.00	0.00

Table 23. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-1 ft.; AADT-1500 vpd

AADT 1500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	22.44	21.77	-0.26
1:3	0.00	0.00	20.59	-1.75
1:6	0.00	0.00	0.00	-2.35
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	44.10	42.88	0.14
1:3	0.00	0.00	40.01	-2.78
1:6	0.00	0.00	0.00	-4.01
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	57.96	53.83	1.53
1:3	0.00	0.00	45.93	-2.21
1:6	0.00	0.00	0.00	-3.94
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	77.20	69.25	1.43
1:3	0.00	0.00	55.38	-3.60
1:6	0.00	0.00	0.00	-5.93
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	96.18	86.97	2.32
1:3	0.00	0.00	70.90	-3.91
1:6	0.00	0.00	0.00	-6.88
Guardrail	0.00	0.00	0.00	0.00

Table 24. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-7 ft.; AADT-250&500 vpd

AADT 250 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	1.73	1.44	0.64
1:3	0.00	0.00	1.11	-0.31
1:6	0.00	0.00	0.00	-1.05
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.19	2.50	1.27
1:3	0.00	0.00	1.25	-0.41
1:6	0.00	0.00	0.00	-1.96
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.40	2.59	1.39
1:3	0.00	0.00	1.50	-0.36
1:6	0.00	0.00	0.00	-3.72
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.64	2.82	1.56
1:3	0.00	0.00	1.83	-0.26
1:6	0.00	0.00	0.00	-5.49
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.81	3.16	1.74
1:3	0.00	0.00	2.38	-0.06
1:6	0.00	0.00	0.00	-6.17
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.42	2.85	1.27
1:3	0.00	0.00	1.61	-0.61
1:6	0.00	0.00	0.00	-2.07
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	6.3	5.02	2.50
1:3	0.00	0.00	2.72	-0.80
1:6	0.00	0.00	0.00	-4.10
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	6.72	5.12	2.74
1:3	0.00	0.00	2.96	-0.71
1:6	0.00	0.00	0.00	-7.33
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	7.19	5.58	3.07
1:3	0.00	0.00	3.61	-0.51
1:6	0.00	0.00	0.00	-10.81
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	7.53	6.25	3.40
1:3	0.00	0.00	4.70	-0.12
1:6	0.00	0.00	0.00	-12.14
Guardrail	0.00	0.00	0.00	0.00

Table 25. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-7 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	4.98	3.71	1.84
1:3	0.00	0.00	1.76	-0.89
1:6	0.00	0.00	0.00	-4.33
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.17	6.62	3.64
1:3	0.00	0.00	3.18	-1.16
1:6	0.00	0.00	0.00	-8.95
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.77	6.93	3.99
1:3	0.00	0.00	3.76	-1.04
1:6	0.00	0.00	0.00	-18.11
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	10.47	7.44	4.47
1:3	0.00	0.00	4.5	-0.74
1:6	0.00	0.00	0.00	-46.44
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	10.96	8.36	5.00
1:3	0.00	0.00	5.85	-0.17
1:6	0.00	0.00	0.00	-52.98
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	6.49	4.83	2.40
1:3	0.00	0.00	2.29	-1.15
1:6	0.00	0.00	0.00	-5.63
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	11.94	8.62	4.73
1:3	0.00	0.00	4.13	-1.51
1:6	0.00	0.00	0.00	-11.62
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	12.72	9.01	5.19
1:3	0.00	0.00	4.89	-1.35
1:6	0.00	0.00	0.00	-23.48
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	13.62	9.68	5.81
1:3	0.00	0.00	5.86	-0.96
1:6	0.00	0.00	0.00	-60.31
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	14.26	10.88	6.51
1:3	0.00	0.00	7.62	-0.22
1:6	0.00	0.00	0.00	-68.37
Guardrail	0.00	0.00	0.00	0.00

Table 26. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-7 ft.; AADT-1500 vpd

AADT 1500 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.29	6.6	3.43
1:3	0.00	0.00	2.96	-1.65
1:6	0.00	0.00	0.00	-9.92
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	17.09	11.85	6.77
1:3	0.00	0.00	5.48	-2.16
1:6	0.00	0.00	0.00	-21.05
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	18.22	12.21	7.42
1:3	0.00	0.00	6.39	-1.93
1:6	0.00	0.00	0.00	-73.13
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	19.51	13.55	8.32
1:3	0.00	0.00	8.1	-1.37
1:6	0.00	0.00	0.00	-170.54
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	20.42	15.25	9.31
1:3	0.00	0.00	10.52	-0.31
1:6	0.00	0.00	0.00	-193.74
Guardrail	0.00	0.00	0.00	0.00

Table 27. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-13 ft.; AADT-250&500 vpd

AADT 250 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.05	0.82	0.76
Guardrail	0.00	0.00	0.34	0.42
1:3	0.00	0.00	0.00	0.53
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.59	1.21	1.12
Guardrail	0.00	0.00	0.40	0.64
1:3	0.00	0.00	0.00	0.86
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.80	1.32	1.19
Guardrail	0.00	0.00	0.30	0.66
1:3	0.00	0.00	0.00	0.91
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.04	1.43	1.31
Guardrail	0.00	0.00	0.14	0.72
1:3	0.00	0.00	0.00	1.08
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.15	1.42	1.41
Guardrail	0.00	0.00	-0.15	0.81
1:3	0.00	0.00	0.00	1.39
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.08	1.63	1.5
Guardrail	0.00	0.00	0.67	0.84
1:3	0.00	0.00	0.00	1.04
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.14	2.39	2.21
Guardrail	0.00	0.00	0.79	1.26
1:3	0.00	0.00	0.00	1.69
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.56	2.61	2.35
Guardrail	0.00	0.00	0.6	1.31
1:3	0.00	0.00	0.00	1.79
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.03	2.83	2.59
Guardrail	0.00	0.00	0.28	1.43
1:3	0.00	0.00	0.00	2.13
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.25	2.8	2.78
Guardrail	0.00	0.00	-0.29	1.6
1:3	0.00	0.00	0.00	2.75
1:6	0.00	0.00	0.00	0.00

Table 28. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-13 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.02	2.37	2.00
Guardrail	0.00	0.00	0.97	1.04
1:3	0.00	0.00	0.00	1.09
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.57	3.48	2.98
Guardrail	0.00	0.00	1.15	1.60
1:3	0.00	0.00	0.00	1.90
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.18	3.80	3.2
Guardrail	0.00	0.00	0.87	1.72
1:3	0.00	0.00	0.00	2.18
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.87	4.12	3.45
Guardrail	0.00	0.00	0.41	1.84
1:3	0.00	0.00	0.00	2.49
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.18	4.08	3.72
Guardrail	0.00	0.00	-0.42	2.07
1:3	0.00	0.00	0.00	3.22
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.93	3.08	2.60
Guardrail	0.00	0.00	1.26	1.35
1:3	0.00	0.00	0.00	1.42
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.94	4.53	3.87
Guardrail	0.00	0.00	1.50	2.08
1:3	0.00	0.00	0.00	2.48
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.73	4.95	4.17
Guardrail	0.00	0.00	1.13	2.24
1:3	0.00	0.00	0.00	2.84
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	7.63	5.37	4.15
Guardrail	0.00	0.00	0.53	1.81
1:3	0.00	0.00	0.00	2.39
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.04	5.30	4.85
Guardrail	0.00	0.00	-0.55	2.70
1:3	0.00	0.00	0.00	4.19
1:6	0.00	0.00	0.00	0.00

Table 29. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-13 ft.; AADT-1500 vpd

AADT 1500 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.63	4.41	3.58
Guardrail	0.00	0.00	1.81	1.81
1:3	0.00	0.00	0.00	1.81
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.50	6.48	5.36
Guardrail	0.00	0.00	2.16	2.82
1:3	0.00	0.00	0.00	3.22
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	9.63	7.08	5.64
Guardrail	0.00	0.00	1.62	2.95
1:3	0.00	0.00	0.00	3.56
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	10.92	7.92	6.28
Guardrail	0.00	0.00	0.77	3.31
1:3	0.00	0.00	0.00	4.39
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	11.51	7.60	6.78
Guardrail	0.00	0.00	-0.78	3.75
1:3	0.00	0.00	0.00	5.68
1:6	0.00	0.00	0.00	0.00

Table 30. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-20 ft.; AADT-250&500 vpd

AADT 250 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.13	0.43	0.37
Guardrail	0.00	0.00	0.06	0.07
1:3	0.00	0.00	0.00	0.09
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.57	0.58	0.52
Guardrail	0.00	0.00	0.07	0.12
1:3	0.00	0.00	0.00	0.25
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.78	0.64	0.56
Guardrail	0.00	0.00	0.05	0.14
1:3	0.00	0.00	0.00	0.33
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.95	0.67	0.60
Guardrail	0.00	0.00	0.01	0.15
1:3	0.00	0.00	0.00	0.42
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.06	0.67	0.63
Guardrail	0.00	0.00	-0.06	0.16
1:3	0.00	0.00	0.00	0.55
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.22	0.84	0.74
Guardrail	0.00	0.00	0.13	0.14
1:3	0.00	0.00	0.00	0.19
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.09	1.15	1.03
Guardrail	0.00	0.00	0.14	0.24
1:3	0.00	0.00	0.00	0.50
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.52	1.24	0.95
Guardrail	0.00	0.00	0.32	0.06
1:3	0.00	0.00	0.00	-1.58
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.84	1.32	1.19
Guardrail	0.00	0.00	0.01	0.31
1:3	0.00	0.00	0.00	0.84
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.07	1.31	1.25
Guardrail	0.00	0.00	-0.11	0.31
1:3	0.00	0.00	0.00	1.08
1:6	0.00	0.00	0.00	0.00

Table 31. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-20 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.24	1.23	1.04
Guardrail	0.00	0.00	0.18	0.23
1:3	0.00	0.00	0.00	0.35
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.50	1.67	1.43
Guardrail	0.00	0.00	0.21	0.36
1:3	0.00	0.00	0.00	0.68
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.12	1.84	1.57
Guardrail	0.00	0.00	0.13	0.43
1:3	0.00	0.00	0.00	0.91
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.59	1.92	1.66
Guardrail	0.00	0.00	0.02	0.49
1:3	0.00	0.00	0.00	1.14
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.93	1.91	1.77
Guardrail	0.00	0.00	-0.17	0.53
1:3	0.00	0.00	0.00	1.46
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.21	1.59	1.35
Guardrail	0.00	0.00	0.24	0.30
1:3	0.00	0.00	0.00	0.46
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.86	2.18	1.86
Guardrail	0.00	0.00	0.27	0.47
1:3	0.00	0.00	0.00	0.89
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.66	2.39	2.04
Guardrail	0.00	0.00	0.17	0.56
1:3	0.00	0.00	0.00	1.18
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	7.63	5.37	4.15
Guardrail	0.00	0.00	0.53	1.81
1:3	0.00	0.00	0.00	2.39
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	7.71	2.49	2.30
Guardrail	0.00	0.00	-0.22	0.69
1:3	0.00	0.00	0.00	1.90
1:6	0.00	0.00	0.00	0.00

Table 32. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-20 ft.; AADT-1500 vpd

AADT 1500 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.02	2.28	1.88
Guardrail	0.00	0.00	0.34	0.44
1:3	0.00	0.00	0.00	0.63
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.38	3.12	2.62
Guardrail	0.00	0.00	0.39	0.69
1:3	0.00	0.00	0.00	1.24
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	9.63	3.34	3.03
Guardrail	0.00	0.00	0.21	0.74
1:3	0.00	0.00	0.00	1.95
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	10.41	3.58	3.23
Guardrail	0.00	0.00	0.03	0.83
1:3	0.00	0.00	0.00	2.27
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	11.04	3.61	3.39
Guardrail	0.00	0.00	-0.31	0.84
1:3	0.00	0.00	0.00	2.92
1:6	0.00	0.00	0.00	0.00

4 ft. Shoulder

Table 33. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-1 ft.; AADT-250&500 vpd

AADT 250 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.53	3.81	-0.05
1:3	0.00	0.00	4.90	-0.28
1:6	0.00	0.00	0.00	-0.38
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	7.06	7.55	0.03
1:3	0.00	0.00	9.23	-0.04
1:6	0.00	0.00	0.00	-0.63
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.19	9.57	0.09
1:3	0.00	0.00	10.6	-0.52
1:6	0.00	0.00	0.00	-0.79
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	12.25	11.61	0.22
1:3	0.00	0.00	10.30	-0.58
1:6	0.00	0.00	0.00	-0.94
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	15.26	14.58	0.36
1:3	0.00	0.00	13.19	-0.63
1:6	0.00	0.00	0.00	-1.09
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.53	3.81	-0.05
1:3	0.00	0.00	4.90	-0.28
1:6	0.00	0.00	0.00	-0.38
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	13.82	14.79	0.03
1:3	0.00	0.00	18.12	-0.88
1:6	0.00	0.00	0.00	-1.26
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	18.16	18.89	0.18
1:3	0.00	0.00	20.94	-1.02
1:6	0.00	0.00	0.00	-1.56
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	24.19	24.54	0.44
1:3	0.00	0.00	25.43	-1.44
1:6	0.00	0.00	0.00	-1.85
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	30.14	30.82	0.72
1:3	0.00	0.00	32.56	-1.24
1:6	0.00	0.00	0.00	-2.15
Guardrail	0.00	0.00	0.00	0.00

Table 34. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-1 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	10.14	10.42	-0.13
1:3	0.00	0.00	11.30	-0.82
1:6	0.00	0.00	0.00	-1.08
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	20.11	20.48	0.05
1:3	0.00	0.00	21.49	-1.29
1:6	0.00	0.00	0.00	-1.84
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	26.44	26.26	0.26
1:3	0.00	0.00	25.85	-1.48
1:6	0.00	0.00	0.00	-2.27
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	35.21	33.37	0.64
1:3	0.00	0.00	29.61	-1.66
1:6	0.00	0.00	0.00	-2.71
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	43.81	41.92	-1.04
1:3	0.00	0.00	37.91	-1.81
1:6	0.00	0.00	0.00	-3.14
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	13.20	13.57	-0.17
1:3	0.00	0.00	14.70	-1.06
1:6	0.00	0.00	0.00	-1.41
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	26.18	26.65	0.06
1:3	0.00	0.00	27.97	-1.67
1:6	0.00	0.00	0.00	-2.40
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	34.41	34.18	0.34
1:3	0.00	0.00	33.65	-1.93
1:6	0.00	0.00	0.00	-2.96
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	45.83	43.44	0.83
1:3	0.00	0.00	38.54	-2.16
1:6	0.00	0.00	0.00	-3.53
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	57.10	54.56	1.36
1:3	0.00	0.00	49.34	-2.35
1:6	0.00	0.00	0.00	-4.09
Guardrail	0.00	0.00	0.00	0.00

Table 35. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-1 ft.; AADT-1500 vpd

AADT 1500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	18.90	18.94	-0.25
1:3	0.00	0.00	19.05	-1.52
1:6	0.00	0.00	0.00	-2.02
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	37.49	37.29	0.09
1:3	0.00	0.00	36.76	-2.39
1:6	0.00	0.00	0.00	-3.44
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	49.28	46.79	0.48
1:3	0.00	0.00	41.71	-2.76
1:6	0.00	0.00	0.00	-4.28
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	45.83	42.47	0.83
1:3	0.00	0.00	36.03	-2.16
1:6	0.00	0.00	0.00	-3.54
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	81.78	76.39	1.94
1:3	0.00	0.00	66.07	-3.37
1:6	0.00	0.00	0.00	-5.86
Guardrail	0.00	0.00	0.00	0.00

Table 36. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-7 ft.; AADT-250&500 vpd

AADT 250 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	1.54	1.38	0.59
1:3	0.00	0.00	0.94	-0.23
1:6	0.00	0.00	0.00	-0.75
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	2.83	2.49	1.18
1:3	0.00	0.00	1.49	-0.26
1:6	0.00	0.00	0.00	-1.42
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.02	2.43	1.30
1:3	0.00	0.00	1.52	-0.20
1:6	0.00	0.00	0.00	-2.47
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.23	2.63	1.45
1:3	0.00	0.00	1.82	-0.10
1:6	0.00	0.00	0.00	-3.56
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.38	2.95	1.62
1:3	0.00	0.00	2.36	0.09
1:6	0.00	0.00	0.00	-4.02
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.04	2.76	1.17
1:3	0.00	0.00	1.86	-0.45
1:6	0.00	0.00	0.00	-1.48
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	5.59	4.76	2.33
1:3	0.00	0.00	2.95	-0.52
1:6	0.00	0.00	0.00	-2.81
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	5.96	4.80	2.56
1:3	0.00	0.00	3.00	-0.40
1:6	0.00	0.00	0.00	-4.86
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	6.39	5.20	2.87
1:3	0.00	0.00	3.59	-0.20
1:6	0.00	0.00	0.00	-7.01
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	6.69	5.83	3.20
1:3	0.00	0.00	4.66	0.17
1:6	0.00	0.00	0.00	-7.92
Guardrail	0.00	0.00	0.00	0.00

Table 37. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-7 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	4.43	3.50	1.70
1:3	0.00	0.00	1.83	-0.66
1:6	0.00	0.00	0.00	-3.00
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.14	6.20	3.38
1:3	0.00	0.00	3.22	-0.75
1:6	0.00	0.00	0.00	-5.93
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.68	6.42	3.72
1:3	0.00	0.00	3.67	-0.59
1:6	0.00	0.00	0.00	-11.22
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.3	6.84	4.17
1:3	0.00	0.00	4.30	-0.28
1:6	0.00	0.00	0.00	-24.61
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.73	7.69	4.66
1:3	0.00	0.00	5.58	0.25
1:6	0.00	0.00	0.00	-28.08
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	5.76	4.55	2.22
1:3	0.00	0.00	2.39	-0.86
1:6	0.00	0.00	0.00	-3.89
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	10.6	8.07	4.40
1:3	0.00	0.00	4.19	-0.98
1:6	0.00	0.00	0.00	-7.71
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	11.3	8.36	4.84
1:3	0.00	0.00	4.78	-0.76
1:6	0.00	0.00	0.00	-14.56
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	12.1	8.90	5.42
1:3	0.00	0.00	5.59	-0.37
1:6	0.00	0.00	0.00	-31.88
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	12.67	10.01	6.06
1:3	0.00	0.00	7.26	0.32
1:6	0.00	0.00	0.00	-36.37
Guardrail	0.00	0.00	0.00	0.00

Table 38. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-7 ft.; AADT-1500 vpd

AADT 1500 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.25	6.18	3.17
1:3	0.00	0.00	3.01	-1.23
1:6	0.00	0.00	0.00	-6.73
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	15.18	11.04	6.30
1:3	0.00	0.00	5.44	-1.40
1:6	0.00	0.00	0.00	-13.61
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	16.18	11.22	6.93
1:3	0.00	0.00	6.09	-1.09
1:6	0.00	0.00	0.00	-38.73
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	17.33	11.96	7.76
1:3	0.00	0.00	6.76	-0.53
1:6	0.00	0.00	0.00	-63.36
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	18.14	13.39	8.67
1:3	0.00	0.00	8.79	0.46
1:6	0.00	0.00	0.00	-71.35
Guardrail	0.00	0.00	0.00	0.00

Table 39. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-13 ft.; AADT-250&500 vpd

AADT 250 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	0.92	0.73	0.65
Guardrail	0.00	0.00	0.23	0.23
1:3	0.00	0.00	0.00	0.24
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.40	1.07	0.93
Guardrail	0.00	0.00	0.20	0.31
1:3	0.00	0.00	0.00	0.42
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.59	1.17	0.98
Guardrail	0.00	0.00	0.07	0.34
1:3	0.00	0.00	0.00	0.52
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.81	1.44	1.27
Guardrail	0.00	0.00	0.45	0.46
1:3	0.00	0.00	0.00	0.47
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.89	1.26	1.12
Guardrail	0.00	0.00	-0.44	0.37
1:3	0.00	0.00	0.00	0.83
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.81	1.44	1.27
Guardrail	0.00	0.00	0.45	0.46
1:3	0.00	0.00	0.00	0.47
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.76	2.12	1.84
Guardrail	0.00	0.00	0.41	0.62
1:3	0.00	0.00	0.00	0.83
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.13	2.32	1.94
Guardrail	0.00	0.00	0.35	0.67
1:3	0.00	0.00	0.00	1.02
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.55	2.52	2.12
Guardrail	0.00	0.00	-0.25	0.72
1:3	0.00	0.00	0.00	1.28
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.74	2.49	2.22
Guardrail	0.00	0.00	-0.87	0.72
1:3	0.00	0.00	0.00	1.65
1:6	0.00	0.00	0.00	0.00

Table 40. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-13 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.64	2.10	1.71
Guardrail	0.00	0.00	0.66	0.61
1:3	0.00	0.00	0.00	0.57
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.02	3.09	2.50
Guardrail	0.00	0.00	0.59	0.88
1:3	0.00	0.00	0.00	1.07
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.56	3.38	2.68
Guardrail	0.00	0.00	0.19	0.97
1:3	0.00	0.00	0.00	1.37
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.16	3.66	2.90
Guardrail	0.00	0.00	-0.36	1.09
1:3	0.00	0.00	0.00	1.70
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.44	3.62	3.06
Guardrail	0.00	0.00	-1.27	1.16
1:3	0.00	0.00	0.00	2.19
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.44	2.74	2.23
Guardrail	0.00	0.00	0.85	0.79
1:3	0.00	0.00	0.00	0.74
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.23	4.02	3.26
Guardrail	0.00	0.00	0.55	1.14
1:3	0.00	0.00	0.00	1.39
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.93	4.39	3.49
Guardrail	0.00	0.00	0.25	1.27
1:3	0.00	0.00	0.00	1.79
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.71	4.77	3.77
Guardrail	0.00	0.00	-0.47	1.41
1:3	0.00	0.00	0.00	2.21
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	7.07	4.71	3.98
Guardrail	0.00	0.00	-1.65	1.51
1:3	0.00	0.00	0.00	2.85
1:6	0.00	0.00	0.00	0.00

Table 41. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-13 ft.; AADT-1500 vpd

AADT 1500 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.92	3.92	3.08
Guardrail	0.00	0.00	0.91	1.09
1:3	0.00	0.00	0.00	1.00
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	7.48	5.76	4.53
Guardrail	0.00	0.00	1.10	1.61
1:3	0.00	0.00	0.00	1.91
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.49	6.29	4.78
Guardrail	0.00	0.00	0.36	1.81
1:3	0.00	0.00	0.00	2.42
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	9.61	6.83	5.30
Guardrail	0.00	0.00	-0.68	2.03
1:3	0.00	0.00	0.00	3.09
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	10.12	6.75	5.61
Guardrail	0.00	0.00	-2.37	2.20
1:3	0.00	0.00	0.00	3.98
1:6	0.00	0.00	0.00	0.00

Table 42. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-20 ft.; AADT-250&500 vpd

AADT 250 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	0.98	0.38	0.35
Guardrail	0.00	0.00	0.07	0.08
1:3	0.00	0.00	0.00	0.13
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.37	0.52	0.47
Guardrail	0.00	0.00	0.08	0.11
1:3	0.00	0.00	0.00	0.24
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.56	0.57	0.51
Guardrail	0.00	0.00	0.06	0.13
1:3	0.00	0.00	0.00	0.31
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.70	0.59	0.55
Guardrail	0.00	0.00	0.02	0.14
1:3	0.00	0.00	0.00	0.40
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.80	0.59	0.57
Guardrail	0.00	0.00	-0.04	0.14
1:3	0.00	0.00	0.00	0.51
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.94	0.75	0.69
Guardrail	0.00	0.00	0.13	0.15
1:3	0.00	0.00	0.00	0.25
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.70	1.02	0.93
Guardrail	0.00	0.00	0.15	0.22
1:3	0.00	0.00	0.00	0.48
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.07	1.12	1.01
Guardrail	0.00	0.00	0.11	0.26
1:3	0.00	0.00	0.00	0.61
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.36	1.17	1.08
Guardrail	0.00	0.00	0.04	0.28
1:3	0.00	0.00	0.00	0.78
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.56	1.17	1.13
Guardrail	0.00	0.00	-0.07	0.28
1:3	0.00	0.00	0.00	1.00
1:6	0.00	0.00	0.00	0.00

Table 43. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-20 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.82	1.09	0.97
Guardrail	0.00	0.00	0.19	0.23
1:3	0.00	0.00	0.00	0.35
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.93	1.49	1.30
Guardrail	0.00	0.00	0.22	0.34
1:3	0.00	0.00	0.00	0.64
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.47	1.63	1.42
Guardrail	0.00	0.00	0.16	0.40
1:3	0.00	0.00	0.00	0.84
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.89	1.70	1.50
Guardrail	0.00	0.00	0.06	0.46
1:3	0.00	0.00	0.00	1.05
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.18	1.70	1.59
Guardrail	0.00	0.00	-0.10	0.49
1:3	0.00	0.00	0.00	1.35
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.67	1.42	1.26
Guardrail	0.00	0.00	0.25	0.30
1:3	0.00	0.00	0.00	0.45
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.67	1.42	1.23
Guardrail	0.00	0.00	0.25	0.30
1:3	0.00	0.00	0.00	0.43
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.82	2.12	1.85
Guardrail	0.00	0.00	0.21	0.52
1:3	0.00	0.00	0.00	1.10
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.32	2.17	1.96
Guardrail	0.00	0.00	0.09	0.57
1:3	0.00	0.00	0.00	1.43
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.74	2.21	2.07
Guardrail	0.00	0.00	-0.13	0.63
1:3	0.00	0.00	0.00	1.76
1:6	0.00	0.00	0.00	0.00

Table 44. Benefit-Cost Ratio Tables of Shoulder Width-4 ft.; Fill Height-20 ft.; AADT-1500 vpd

AADT 1500 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.25	2.03	1.72
Guardrail	0.00	0.00	0.36	0.43
1:3	0.00	0.00	0.00	0.59
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.84	2.52	2.12
Guardrail	0.00	0.00	0.32	0.59
1:3	0.00	0.00	0.00	1.18
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.33	3.04	2.60
Guardrail	0.00	0.00	0.30	0.77
1:3	0.00	0.00	0.00	1.53
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	9.11	3.18	2.76
Guardrail	0.00	0.00	0.10	0.87
1:3	0.00	0.00	0.00	1.92
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	9.65	3.17	2.94
Guardrail	0.00	0.00	-0.19	0.94
1:3	0.00	0.00	0.00	2.47
1:6	0.00	0.00	0.00	0.00

6 ft. **Shoulder**

Table 45. Benefit-Cost ratio Tables of Shoulder Width-6 ft.; Fill Height-1 ft.; AADT-250&500 vpd

AADT 250 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.27	3.54	-0.04
1:3	0.00	0.00	4.57	-0.26
1:6	0.00	0.00	0.00	-0.35
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	6.48	7.12	0.02
1:3	0.00	0.00	9.55	-0.41
1:6	0.00	0.00	0.00	-0.59
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.65	12.55	0.11
1:3	0.00	0.00	11.12	-0.48
1:6	0.00	0.00	0.00	-0.71
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	11.35	11.79	0.21
1:3	0.00	0.00	13.01	-0.53
1:6	0.00	0.00	0.00	-0.86
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	14.14	14.80	0.34
1:3	0.00	0.00	16.65	-0.58
1:6	0.00	0.00	0.00	-1.00
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	6.46	6.98	-0.08
1:3	0.00	0.00	9.02	-0.52
1:6	0.00	0.00	0.00	-0.68
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	12.80	14.06	0.04
1:3	0.00	0.00	18.87	-0.81
1:6	0.00	0.00	0.00	-1.16
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	16.83	17.96	0.17
1:3	0.00	0.00	21.47	-0.94
1:6	0.00	0.00	0.00	-1.43
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	22.41	23.28	0.41
1:3	0.00	0.00	25.69	-1.05
1:6	0.00	0.00	0.00	-1.71
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	27.93	29.94	0.67
1:3	0.00	0.00	32.90	-1.14
1:6	0.00	0.00	0.00	-1.97
Guardrail	0.00	0.00	0.00	0.00

Table 46. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-1 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.40	9.90	-0.12
1:3	0.00	0.00	11.62	-0.75
1:6	0.00	0.00	0.00	-1.00
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	18.64	19.47	0.05
1:3	0.00	0.00	22.03	-1.19
1:6	0.00	0.00	0.00	-1.70
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	24.5	24.90	0.25
1:3	0.00	0.00	25.94	-1.36
1:6	0.00	0.00	0.00	-2.09
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	32.63	31.61	0.60
1:3	0.00	0.00	29.39	-1.53
1:6	0.00	0.00	0.00	-2.50
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	40.65	39.70	0.98
1:3	0.00	0.00	37.63	-1.66
1:6	0.00	0.00	0.00	-2.89
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	12.23	12.89	-0.15
1:3	0.00	0.00	15.12	-0.98
1:6	0.00	0.00	0.00	-1.30
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	24.26	23.54	0.07
1:3	0.00	0.00	28.68	-1.54
1:6	0.00	0.00	0.00	-2.21
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	31.88	32.41	0.32
1:3	0.00	0.00	33.77	-1.77
1:6	0.00	0.00	0.00	-2.72
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	44.21	43.41	1.06
1:3	0.00	0.00	40.97	-2.08
1:6	0.00	0.00	0.00	-3.40
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	52.91	51.68	1.27
1:3	0.00	0.00	48.97	-2.16
1:6	0.00	0.00	0.00	-3.76
Guardrail	0.00	0.00	0.00	0.00

Table 47. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-1 ft.; AADT-1500 vpd

AADT 1500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	17.52	18.01	-0.22
1:3	0.00	0.00	19.52	-1.40
1:6	0.00	0.00	0.00	-1.80
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	29.65	33.52	0.21
1:3	0.00	0.00	33.65	-1.98
1:6	0.00	0.00	0.00	-2.56
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	45.66	44.32	0.47
1:3	0.00	0.00	41.40	-2.54
1:6	0.00	0.00	0.00	-3.91
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	68.82	57.66	1.12
1:3	0.00	0.00	51.18	-2.85
1:6	0.00	0.00	0.00	-4.66
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	0.00	75.77	72.41	1.82
1:3	0.00	0.00	65.52	-3.09
1:6	0.00	0.00	0.00	-5.40
Guardrail	0.00	0.00	0.00	0.00

Table 48. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-7 ft.; AADT-250&500 vpd

AADT 250 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	1.36	1.33	0.50
1:3	0.00	0.00	1.18	-0.25
1:6	0.00	0.00	0.00	-0.62
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	2.04	1.98	0.78
1:3	0.00	0.00	1.41	-0.26
1:6	0.00	0.00	0.00	-1.33
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	2.67	2.27	1.09
1:3	0.00	0.00	1.53	-0.28
1:6	0.00	0.00	0.00	-2.00
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	2.86	2.43	1.22
1:3	0.00	0.00	1.78	-0.20
1:6	0.00	0.00	0.00	-2.80
Guardrail	0.00	0.00	0.00	0.00

AADT 250 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.00	2.73	1.37
1:3	0.00	0.00	2.31	-0.05
1:6	0.00	0.00	0.00	-3.15
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	2.69	2.62	0.99
1:3	0.00	0.00	2.34	-0.48
1:6	0.00	0.00	0.00	-1.23
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	4.95	4.52	1.97
1:3	0.00	0.00	3.28	-0.63
1:6	0.00	0.00	0.00	-2.36
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	5.28	4.47	2.15
1:3	0.00	0.00	3.03	-0.56
1:6	0.00	0.00	0.00	-3.94
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	5.55	4.98	2.44
1:3	0.00	0.00	3.84	-0.22
1:6	0.00	0.00	0.00	-5.14
Guardrail	0.00	0.00	0.00	0.00

AADT 500 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	5.92	5.39	2.70
1:3	0.00	0.00	4.57	-0.09
1:6	0.00	0.00	0.00	-6.20
Guardrail	0.00	0.00	0.00	0.00

Table 49. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-7 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	3.92	3.29	1.44
1:3	0.00	0.00	1.92	-0.71
1:6	0.00	0.00	0.00	-2.44
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	7.21	5.79	2.86
1:3	0.00	0.00	3.25	-0.92
1:6	0.00	0.00	0.00	-4.83
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	7.86	5.85	3.25
1:3	0.00	0.00	3.29	-0.66
1:6	0.00	0.00	0.00	-7.65
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.23	5.91	3.51
1:3	0.00	0.00	3.33	-0.58
1:6	0.00	0.00	0.00	-14.58
Guardrail	0.00	0.00	0.00	0.00

AADT 750 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	8.61	6.59	3.93
1:3	0.00	0.00	4.34	-0.14
1:6	0.00	0.00	0.00	-16.12
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	5.1	4.28	1.88
1:3	0.00	0.00	2.50	-0.92
1:6	0.00	0.00	0.00	-3.17
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.38	7.54	3.72
1:3	0.00	0.00	4.23	-1.20
1:6	0.00	0.00	0.00	-6.28
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	9.89	7.61	4.17
1:3	0.00	0.00	4.29	-0.98
1:6	0.00	0.00	0.00	-10.51
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	10.71	7.69	4.57
1:3	0.00	0.00	4.34	-0.76
1:6	0.00	0.00	0.00	-18.91
Guardrail	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	11.21	8.58	5.12
1:3	0.00	0.00	5.65	-0.18
1:6	0.00	0.00	0.00	-20.92
Guardrail	0.00	0.00	0.00	0.00

Table 50. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-7 ft.; AADT-1500 vpd

AADT 1500 DS 45 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	7.30	5.78	2.69
1:3	0.00	0.00	3.04	-1.31
1:6	0.00	0.00	0.00	-5.38
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	13.44	10.24	5.33
1:3	0.00	0.00	5.34	-1.71
1:6	0.00	0.00	0.00	-10.88
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	14.32	9.78	5.84
1:3	0.00	0.00	4.73	-1.52
1:6	0.00	0.00	0.00	-23.65
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	15.34	11.3	6.89
1:3	0.00	0.00	7.13	-0.44
1:6	0.00	0.00	0.00	-40.22
Guardrail	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H7

	1:1	1:3	1:6	Guardrail
1:1	0.00	16.06	12.71	7.70
1:3	0.00	0.00	9.26	0.44
1:6	0.00	0.00	0.00	-45.92
Guardrail	0.00	0.00	0.00	0.00

Table 51. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-13 ft.; AADT-250&500 vpd

AADT 250 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	0.77	0.65	0.66
Guardrail	0.00	0.00	0.31	0.47
1:3	0.00	0.00	0.00	0.76
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.11	0.91	0.92
Guardrail	0.00	0.00	0.35	0.63
1:3	0.00	0.00	0.00	0.99
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.32	1.04	1.01
Guardrail	0.00	0.00	0.28	0.64
1:3	0.00	0.00	0.00	0.93
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.50	1.13	1.11
Guardrail	0.00	0.00	0.13	0.69
1:3	0.00	0.00	0.00	1.05
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.58	1.12	1.19
Guardrail	0.00	0.00	-0.13	0.76
1:3	0.00	0.00	0.00	1.36
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.52	1.28	1.31
Guardrail	0.00	0.00	0.62	0.92
1:3	0.00	0.00	0.00	1.50
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.30	1.88	1.91
Guardrail	0.00	0.00	0.74	1.31
1:3	0.00	0.00	0.00	2.05
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.64	2.05	2.09
Guardrail	0.00	0.00	0.43	1.33
1:3	0.00	0.00	0.00	2.06
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.96	2.23	2.19
Guardrail	0.00	0.00	0.26	1.35
1:3	0.00	0.00	0.00	2.08
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.12	2.20	2.34
Guardrail	0.00	0.00	-0.26	1.51
1:3	0.00	0.00	0.00	2.69
1:6	0.00	0.00	0.00	0.00

Table 52. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-13 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.22	1.86	1.72
Guardrail	0.00	0.00	0.90	1.05
1:3	0.00	0.00	0.00	1.20
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.35	2.74	2.54
Guardrail	0.00	0.00	1.07	1.57
1:3	0.00	0.00	0.00	1.96
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.80	3.04	2.64
Guardrail	0.00	0.00	0.65	1.63
1:3	0.00	0.00	0.00	2.06
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.31	3.24	2.88
Guardrail	0.00	0.00	0.38	1.67
1:3	0.00	0.00	0.00	2.26
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.54	3.21	3.10
Guardrail	0.00	0.00	-0.38	1.88
1:3	0.00	0.00	0.00	2.92
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.89	2.42	2.23
Guardrail	0.00	0.00	1.18	1.37
1:3	0.00	0.00	0.00	1.56
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.36	3.56	3.30
Guardrail	0.00	0.00	1.40	2.04
1:3	0.00	0.00	0.00	2.55
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.94	3.89	3.51
Guardrail	0.00	0.00	1.05	2.09
1:3	0.00	0.00	0.00	2.70
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.47	4.07	3.86
Guardrail	0.00	0.00	0.47	2.24
1:3	0.00	0.00	0.00	3.51
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.91	4.17	4.04
Guardrail	0.00	0.00	-0.50	2.45
1:3	0.00	0.00	0.00	3.81
1:6	0.00	0.00	0.00	0.00

Table 53. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-13 ft.; AADT-1500 vpd

AADT 1500 DS 45 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.13	3.47	3.06
Guardrail	0.00	0.00	1.69	1.78
1:3	0.00	0.00	0.00	1.86
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.25	5.1	4.54
Guardrail	0.00	0.00	2.00	2.7
1:3	0.00	0.00	0.00	3.16
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	7.08	5.57	4.71
Guardrail	0.00	0.00	1.51	2.69
1:3	0.00	0.00	0.00	3.23
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.02	6.05	5.22
Guardrail	0.00	0.00	0.72	2.98
1:3	0.00	0.00	0.00	3.93
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H13

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.45	5.98	5.63
Guardrail	0.00	0.00	-0.71	3.36
1:3	0.00	0.00	0.00	5.08
1:6	0.00	0.00	0.00	0.00

Table 54. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-20 ft.; AADT-250&500 vpd

AADT 250 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	0.87	0.33	0.32
Guardrail	0.00	0.00	0.06	0.07
1:3	0.00	0.00	0.00	0.13
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.22	0.46	0.42
Guardrail	0.00	0.00	0.07	0.08
1:3	0.00	0.00	0.00	0.17
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.38	0.50	0.46
Guardrail	0.00	0.00	0.05	0.11
1:3	0.00	0.00	0.00	0.29
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.51	0.52	0.49
Guardrail	0.00	0.00	0.01	0.12
1:3	0.00	0.00	0.00	0.37
1:6	0.00	0.00	0.00	0.00

AADT 250 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.60	0.52	0.51
Guardrail	0.00	0.00	-0.03	0.12
1:3	0.00	0.00	0.00	0.47
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	1.72	0.66	0.63
Guardrail	0.00	0.00	0.11	0.13
1:3	0.00	0.00	0.00	0.26
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.40	0.90	0.83
Guardrail	0.00	0.00	0.13	0.17
1:3	0.00	0.00	0.00	0.34
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.73	0.99	0.91
Guardrail	0.00	0.00	0.09	0.22
1:3	0.00	0.00	0.00	0.58
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.98	1.04	0.97
Guardrail	0.00	0.00	0.03	0.24
1:3	0.00	0.00	0.00	0.73
1:6	0.00	0.00	0.00	0.00

AADT 500 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.16	1.03	1.01
Guardrail	0.00	0.00	-0.07	0.23
1:3	0.00	0.00	0.00	0.94
1:6	0.00	0.00	0.00	0.00

Table 55. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-20 ft.; AADT-750&1000 vpd

AADT 750 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	2.50	0.96	0.86
Guardrail	0.00	0.00	0.17	0.20
1:3	0.00	0.00	0.00	0.34
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.49	1.31	1.18
Guardrail	0.00	0.00	0.19	0.30
1:3	0.00	0.00	0.00	0.60
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.97	1.44	1.28
Guardrail	0.00	0.00	0.13	0.35
1:3	0.00	0.00	0.00	0.78
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.34	1.51	1.35
Guardrail	0.00	0.00	0.04	0.40
1:3	0.00	0.00	0.00	0.97
1:6	0.00	0.00	0.00	0.00

AADT 750 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.60	1.50	1.43
Guardrail	0.00	0.00	-0.10	0.42
1:3	0.00	0.00	0.00	1.25
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	3.26	1.25	1.12
Guardrail	0.00	0.00	0.22	0.26
1:3	0.00	0.00	0.00	0.41
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.54	1.71	1.54
Guardrail	0.00	0.00	0.24	0.39
1:3	0.00	0.00	0.00	0.78
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.17	1.88	1.67
Guardrail	0.00	0.00	0.17	0.45
1:3	0.00	0.00	0.00	1.02
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.65	1.96	1.76
Guardrail	0.00	0.00	0.05	0.52
1:3	0.00	0.00	0.00	1.27
1:6	0.00	0.00	0.00	0.00

AADT 1000 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	5.99	1.96	1.86
Guardrail	0.00	0.00	-0.13	0.54
1:3	0.00	0.00	0.00	1.63
1:6	0.00	0.00	0.00	0.00

Table 56. Benefit-Cost Ratio Tables of Shoulder Width-6 ft.; Fill Height-20 ft.; AADT-1500 vpd

AADT 1500 DS 45 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	4.66	1.80	1.56
Guardrail	0.00	0.00	0.31	0.38
1:3	0.00	0.00	0.00	0.56
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 55 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	6.50	2.45	2.15
Guardrail	0.00	0.00	0.35	0.57
1:3	0.00	0.00	0.00	1.08
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 60 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	7.40	2.69	2.31
Guardrail	0.00	0.00	0.25	0.68
1:3	0.00	0.00	0.00	1.38
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 65 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.09	2.81	2.49
Guardrail	0.00	0.00	0.08	0.76
1:3	0.00	0.00	0.00	1.77
1:6	0.00	0.00	0.00	0.00

AADT 1500 DS 70 H20

	1:1	Guardrail	1:3	1:6
1:1	0.00	8.57	2.80	2.60
Guardrail	0.00	0.00	-0.19	0.81
1:3	0.00	0.00	0.00	2.28
1:6	0.00	0.00	0.00	0.00

RSAPv3 Benefit-Cost Ratio Tables

Table 57. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-1 ft.; AADT-250&500 vpd (RSAPv3)

AADT 250 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-1.65	-0.13	-0.62
1:3	-	0.00	5.07	-0.56
1:6	-	-	0.00	-0.66
Guardrail	-	-	-	0.00

AADT 250 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-2.4	0.58	-0.57
1:3	-	0.00	9.78	-0.45
1:6	-	-	0.00	-0.66
Guardrail	-	-	-	0.00

AADT 250 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.72	0.11	-0.96
1:3	-	0.00	9.92	-0.79
1:6	-	-	0.00	-1.06
Guardrail	-	-	-	0.00

AADT 250 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.72	0.14	-0.96
1:3	-	0.00	9.29	-0.79
1:6	-	-	0.00	-1.06
Guardrail	-	-	-	0.00

AADT 250 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-6.67	-1.29	-1.53
1:3	-	0.00	6.35	-0.45
1:6	-	-	0.00	-0.59
Guardrail	-	-	-	0.00

AADT 500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.12	-1.28	-0.72
1:3	-	0.00	-4.53	-0.75
1:6	-	-	0.00	-0.68
Guardrail	-	-	-	0.00

AADT 500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-2.9	-0.26	-0.57
1:3	-	0.00	6.35	-0.45
1:6	-	-	0.00	-0.59
Guardrail	-	-	-	0.00

AADT 500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.12	0.47	-0.61
1:3	-	0.00	9.66	-0.45
1:6	-	-	0.00	-0.7
Guardrail	-	-	-	0.00

AADT 500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.72	0.14	-0.96
1:3	-	0.00	9.29	-0.79
1:6	-	-	0.00	-1.06
Guardrail	-	-	-	0.00

AADT 500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-6.67	-1.29	-1.53
1:3	-	0.00	11.44	-1.21
1:6	-	-	0.00	-1.56
Guardrail	-	-	-	0.00

Table 58. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-1 ft.; AADT-750&1000 vpd (RSAPv3)

AADT 750 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-0.17	-0.88	-0.39
1:3	-	0.00	-2.83	-0.41
1:6	-	-	0.00	-0.35
Guardrail	-	-	-	0.00

AADT 750 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-1.26	-0.62	-0.31
1:3	-	0.00	5.44	-0.24
1:6	-	-	0.00	-0.39
Guardrail	-	-	-	0.00

AADT 750 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-1.63	0.22	-0.33
1:3	-	0.00	4.27	-0.24
1:6	-	-	0.00	-0.38
Guardrail	-	-	-	0.00

AADT 750 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-2.93	-1.41	-0.77
1:3	-	0.00	1.49	-0.63
1:6	-	-	0.00	-0.7
Guardrail	-	-	-	0.00

AADT 750 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-5.25	-0.89	-1.22
1:3	-	0.00	7.46	-0.97
1:6	-	-	0.00	-1.26
Guardrail	-	-	-	0.00

AADT 1000 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-0.26	-1.31	-0.58
1:3	-	0.00	-4.25	-0.6
1:6	-	-	0.00	-0.51
Guardrail	-	-	-	0.00

AADT 1000 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-2.4	1.19	-0.57
1:3	-	0.00	10.37	-0.45
1:6	-	-	0.00	-0.72
Guardrail	-	-	-	0.00

AADT 1000 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.12	0.41	-0.61
1:3	-	0.00	8.41	-0.45
1:6	-	-	0.00	-0.7
Guardrail	-	-	-	0.00

AADT 1000 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.72	-1.80	-0.96
1:3	-	0.00	1.90	-0.79
1:6	-	-	0.00	-0.88
Guardrail	-	-	-	0.00

AADT 1000 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-6.67	-1.13	-1.53
1:3	-	0.00	9.48	-1.21
1:6	-	-	0.00	-1.57
Guardrail	-	-	-	0.00

Table 59. Benefit-Cost Ratio Tables of Shoulder Width-2 ft.; Fill Height-1 ft.; AADT-1500 vpd (RSAPv3)

AADT 1500 DS 45 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-0.33	-1.67	-0.72
1:3	-	0.00	-5.40	-0.75
1:6	-	-	0.00	-0.64
Guardrail	-	-	-	0.00

AADT 1500 DS 55 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-2.4	1.19	-0.57
1:3	-	0.00	10.37	-0.45
1:6	-	-	0.00	-0.72
Guardrail	-	-	-	0.00

AADT 1500 DS 60 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.12	0.70	-0.61
1:3	-	0.00	3.94	-0.45
1:6	-	-	0.00	-0.6
Guardrail	-	-	-	0.00

AADT 1500 DS 65 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-3.72	-1.22	-0.96
1:3	-	0.00	2.97	-0.79
1:6	-	-	0.00	-0.94
Guardrail	-	-	-	0.00

AADT 1500 DS 70 H1

	1:1	1:3	1:6	Guardrail
1:1	1.00	-6.67	-1.28	-1.53
1:3	-	0.00	7.71	-1.21
1:6	-	-	0.00	-1.56
Guardrail	-	-	-	0.00

Table 60. Benefit-Cost Ratio Tables of RSAPv3 runs for AADT-1500; DS 70; Fill Heights 1 ft. & 7 ft.; Shoulder widths-2 ft., 4 ft., & 6ft.

AADT 1500 DS 70 H1-2 ft. Shoulder

	1:1	1:3	1:6	Guardrail
1:1	1.00	-6.67	-1.28	-1.53
1:3	-	0.00	7.71	-1.21
1:6	-	-	0.00	-1.56
Guardrail	-	-	-	0.00

AADT 1500 DS 70 H1-4 ft. Shoulder

	1:1	1:3	1:6	Guardrail
1:1	1.00	-4.31	-1.37	-1.29
1:3	-	0.00	3.54	-1.1
1:6	-	-	0.00	-1.28
Guardrail	-	-	-	0.00

AADT 1500 DS 70 H1-6 ft. Shoulder

	1:1	1:3	1:6	Guardrail
1:1	1.00	-4.28	-0.43	-1.21
1:3	-	0.00	6.00	-1.01
1:6	-	-	0.00	-1.29
Guardrail	-	-	-	0.00

AADT 1500 DS 70 H7-2 ft. Shoulder

	1:1	1:3	1:6	Guardrail
1:1	1.00	-0.24	-0.15	-0.12
1:3	-	0.00	-0.07	-0.01
1:6	-	-	0.00	-0.77
Guardrail	-	-	-	0.00

AADT 1500 DS 70 H7-4 ft. Shoulder

	1:1	1:3	1:6	Guardrail
1:1	1.00	-0.86	-0.41	-0.40
1:3	-	0.00	-0.05	-0.03
1:6	-	-	0.00	-0.54
Guardrail	-	-	-	0.00

AADT 1500 DS 70 H7-6 ft. Shoulder

	1:1	1:3	1:6	Guardrail
1:1	1.00	-0.77	-0.49	-0.43
1:3	-	0.00	-0.27	-0.12
1:6	-	-	0.00	-1.16
Guardrail	-	-	-	0.00

Table 61. Benefit-Cost Ratio Tables of RSAPv3 runs for AADT-1500; DS 70; Fill Heights 13 ft. & 20 ft.; Shoulder widths-2 ft., 4 ft., & 6ft.

AADT 1500 DS 70 H13-2 ft. Shoulder

	1:1	Guardrail	1:3	1:6
1:1	0.00	-0.51	0.12	-0.1
Guardrail	-	0.00	0.98	0.20
1:3	-	-	0.00	-0.08
1:6	-	-	-	0.00

AADT 1500 DS 70 H13-4 ft. Shoulder

	1:1	Guardrail	1:3	1:6
1:1	0.00	-0.74	-0.27	-0.14
Guardrail	-	0.00	1.11	0.30
1:3	-	-	0.00	0.02
1:6	-	-	-	0.00

AADT 1500 DS 70 H13-6 ft. Shoulder

	1:1	Guardrail	1:3	1:6
1:1	0.00	-0.6	-0.27	-0.13
Guardrail	-	0.00	0.67	0.22
1:3	-	-	0.00	0.06
1:6	-	-	-	0.00

AADT 1500 DS 70 H20-2 ft. Shoulder

	1:1	Guardrail	1:3	1:6
1:1	0.00	-0.23	-0.04	-0.05
Guardrail	-	0.00	0.5	0.09
1:3	-	-	0.00	-0.06
1:6	-	-	-	0.00

AADT 1500 DS 70 H20-4 ft. Shoulder

	1:1	Guardrail	1:3	1:6
1:1	0.00	-0.86	-0.26	-0.15
Guardrail	-	0.00	1.70	0.41
1:3	-	-	0.00	0.01
1:6	-	-	-	0.00

AADT 1500 DS 70 H20-6 ft. Shoulder

	1:1	Guardrail	1:3	1:6
1:1	0.00	-0.69	-0.28	-0.13
Guardrail	-	0.00	1.07	0.30
1:3	-	-	0.00	0.06
1:6	-	-	-	0.00